

PLANT PATHOLOGY

Introductory Plant Pathology

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Importance of the Plant Diseases

Globally, enormous losses of the crops are caused by the plant diseases. The loss can occur from the time of seed sowing in the field to harvesting and storage. Important historical evidences of plant disease epidemics are Irish Famine due to late blight of potato (Ireland, 1845), Bengal famine due to brown spot of rice (India, 1942) and Coffee rust (Sri Lanka, 1967). Such epidemics had left their effect on the economy of the affected countries.

Objectives of Plant Pathology

Plant Pathology (Phytopathology) deals with the cause, etiology, resulting losses and control or management of the plant diseases. The objectives of the Plant Pathology are the study on:

- i. the living entities that cause diseases in plants;
- ii. the non-living entities and the environmental conditions that cause disorders in plants;
- iii. the mechanisms by which the disease causing agents produce diseases;
- iv. the interactions between the disease causing agents and host plant in relation to overall environment; and
- v. the method of preventing or management the diseases and reducing the losses/damages caused by diseases.

Scope of Plant Pathology

Plant pathology comprises with the basic knowledge and technologies of Botany, Plant Anatomy, Plant Physiology, Mycology, Bacteriology, Virology, Nematology, Genetics, Molecular Biology, Genetic Engineering, Biochemistry, Horticulture, Tissue Culture, Soil Science, Forestry, Physics, Chemistry, Meteorology, Statistics and many other branches of applied science.

Concept of Plant Disease

The normal physiological functions of plants are disturbed when they are affected by pathogenic living organisms or by some environmental factors. Initially plants react to the disease causing agents, particularly in the site of infection. Later, the reaction becomes more widespread and histological changes take place. Such changes are expressed as different types of symptoms of the disease which can be visualized macroscopically. As a result of the disease, plant growth is reduced, deformed or even the plant dies.

When a plant is suffering, we call it diseased, i.e. it is at 'dis-ease'. Disease is a condition that occurs in consequence of abnormal changes in the form, physiology, integrity or behaviour of the plant. According to American Phytopathological Society (*Phytopathology* 30:361-368, 1940), disease is a deviation from normal functioning of physiological processes of sufficient duration or intensity to cause disturbance or cessation of vital activities. The British Mycological Society (*Trans. Brit. Mycol. Soc.* 33:154-160, 1950) defined the disease as a harmful deviation from the normal functioning of process. Recently, Encyclopedia Britannica (2002) forwarded a simplified definition of plant disease. A plant is diseased when it is continuously disturbed by some causal agent that results in abnormal physiological process that disrupts the plants normal structure, growth, function or other activities. This interference with one or more plant's essential physiological or biochemical systems elicits characteristic pathological conditions or symptoms.

Causes of Plant Diseases

Plant diseases are caused by pathogens. Hence a pathogen is always associated with a disease. In other way, disease is a symptom caused by the invasion of a pathogen that is able to survive, perpetuate and spread. Further, the word “pathogen” can be broadly defined as any agent or factor that incites 'pathos or disease in an organism or host. In strict sense, the causes of plant diseases are grouped under following categories:

1. Animate or biotic causes: Pathogens of living nature are categorized into the following groups.

(i) Fungi	(v) Algae
(ii) Bacteria	(vi) Phanerogams
(iii) Phytoplasma	(vii) Protozoa
(iv) Rickettsia-like organisms	(viii) Nematodes

2. Mesobiotic causes : These disease incitants are neither living or non-living, e.g.

- (i) Viruses
- (ii) Viroides

3. Inanimate or abiotic causes: In true sense these factors cause damages (any reduction in the quality or quantity of yield or loss of revenue) to the plants rather than causing disease. The causes are:

- (i) Deficiencies or excess of nutrients (e.g. 'Khaira' disease of rice due to Zn deficiency)
- (ii) Light
- (iii) Moisture
- (iv) Temperature
- (v) Air pollutants (e.g. black tip of mango)
- (vi) Lack of oxygen (e.g. hollow and black heart of potato)
- (vii) Toxicity of pesticides
- (viii) Improper cultural practices
- (ix) Abnormality in soil conditions (acidity, alkalinity)

Classification of Plant Disease

To facilitate the study of plant diseases they are needed to be grouped in some orderly fashion. Plant diseases can be grouped in various ways based on the symptoms or signs (rust, smut, blight etc.), nature of infection (systemic or localized), habitat of the pathogens, mode of perpetuation and spread (soil-, seed- and air-borne etc.), affected parts of the host (aerial, root disease etc.), types of the plants (cereals, pulses, oilseed, ornamental, vegetable, forest diseases etc.). But the most useful classification has been made based on the type of pathogens that cause plant diseases. Since this type of classification indicates not only the cause of the disease, but also the knowledge and information that suggest the probable development and spread of disease alongwith their possible control measures. The classification is as follows:

1. Infectious plant diseases:

- a. Disease caused by parasitic organisms: The organisms included in animate or biotic causes can incite diseases in plants.
- b. Diseases caused by viruses and viroids.

2. Non-infectious or non-parasitic or physiological diseases: The factors included in inanimate or abiotic causes can incite such diseases in plants under a set of suitable environmental conditions.

Definition and terms

1. **Parasite:** An organism living upon or in another living organism (the host) and obtaining the food from the invading host.
2. **Pathogen:** An entity, usually a micro-organism that can cause the disease.
3. **Biotroph:** A plant pathogenic fungus that requires living host cells i.e. an obligate parasite.
4. **Hemibiotroph:** A plant pathogenic fungus that initially requires living host cells but after killing the host cell grows on the dead and dying cells.
5. **Necrotroph:** A pathogenic fungus that kills the host and survives on the dying and dead cells.
6. **Pathogenicity:** The relative capability of a pathogen to cause disease.
7. **Pathogenesis:** It is a process caused by an infectious agent (pathogen) when it comes in contact with a susceptible host.
8. **Virulence:** The degree of infectivity of a given pathogen.
9. **Infection:** The initiation and establishment of a parasite within a host plant.
10. **Primary infection:** The first infection of a plant by the over wintering or over summering of the pathogen.
11. **Inoculum:** That portion of pathogen which is transferred to plant and cause disease.
12. **Invasion:** The penetration and spread of a pathogen in the host.
13. **Colonization:** The growth of a pathogen, particularly a fungus, in the host after infection is called colonization.
14. **Inoculum potential:** The growth or threshold of fungus available for colonization at substratum (host).
15. **Symptoms:** The external and internal reaction or alterations of a plant as a result of disease.
16. **Incubation period:** The period of time between penetration of a pathogen to the host and the first appearance of symptoms on the plant.
17. **Disease cycle:** The chain of events involved in disease development.
18. **Disease syndrome:** The set of varying symptoms characterizing a disease are collectively called a syndrome.
19. **Single cycle disease** (Monocyclic): This type of disease is referred to those caused by the pathogen (fungi) that can complete only one life cycle in one crop season of the host plant. e.g. downy mildew of rapeseed, club root of crucifers, sclerotinia blight of brinjal etc.
20. **Multiple cycle disease** (Polycyclic): Some pathogens specially a fungus, can complete a number of life cycles within one crop season of the host plant and the disease caused by such pathogens is called multiple cycle disease e.g. wheat rust, rice blast, late blight of potato etc.
21. **Alternate host:** Plants not related to the main host of parasitic fungus, where it produces its different stages to complete one cycle (heteroecious).
22. **Collateral host:** The wild host of same families of a pathogen is called as collateral host.

23. **Predisposition:** The effect of one or more environmental factors which makes a plant vulnerable to attack by a pathogen.

24. **Physiologic race:** One or a group of microorganisms similar in morphology but dissimilar in certain cultural, physiological or pathological characters.

25. **Biotype:** The smallest morphological unit within a species, the members of which are usually genetically identical.

26. **Symbiosis:** A mutually beneficial association of two or more different kinds of organisms.

27. **Mutualism:** Symbiosis of two organisms that are mutually helpful or that mutually support one another.

28. **Antagonism:** The counteraction between organisms or groups of organisms.

29. **Mutation:** An abrupt appearance of a new characteristic in an individual as a result of an accidental change in genes present in chromosomes.

30. **Disease:** Any deviation in the general health, or physiology or function of plant or plant parts, is recognized as a disease.

31. **Crop Damage:** It is defined as any reduction in the quality or quantity of yield or loss of revenue resulting from crop injury.

32. **Deficiency:** Abnormality or disease caused by the lack or subnormal level of availability of one or more essential nutrient elements.

History of Plant Pathology with special reference to Indian works

Historical perspectives show that the attention of man to plant diseases and the science of plant pathology were drawn first only in the European countries. Greek philosopher Theophrastus (about 286 BC) recorded some plant diseases about 2400 years ago. This branch of science could maintain a proper record on the plant disease and their causal organisms only after development of compound microscope by the Dutch worker Antony von Leeuwenhoek in 1675. He first visualized bacteria in 1683 under his microscope. Robert Hook (1635-1703) also developed simple microscope which was used to study of minute structure of fungi. The Italian botanist Pier' Antonio Micheli (1679-1737) first made detail study of fungi in 1729. With the contribution of many other scientists' viz., Mathieu Tillet (1755), Christian Hendrik Persoon (1801) and Elias Magnus Fries (1821), the foundation of modern plant pathology was built and was further strengthened by Anton de Bary (1831-1888), who is regarded as the Father of Plant Pathology.

Historically, plant pathology of India is quite ancient as the Indian agriculture, which is nearly 4000 years old. This confirms that mention about plant diseases was made much before the time of Theophrastus. The events of the development of plant pathology in India are chronologically recorded as follows:

- (i) Plant diseases, other enemies of plants and methods of their control had been recorded in the ancient books viz., *Rigveda*, *Atharva Veda* (1500-500 BC), *Artha Shastra* of Kautilya (321-186 BC), *Sushruta Samhita* (200-500AD), *Vishnu Purana* (500 AD), *Agnipurana* (500-700 AD), *Vishnudharmottara* (500-700 AD) etc.

- (ii) During 11th century, Surapal wrote *Vraksha Ayurveda*, which is the first book in India where he gave detail account on plant diseases and their control. Plant diseases were grouped into two-internal and external. Tree surgery, hygiene protective covering with paste, use of honey, plant extracts, oil cakes of mustard, castor, sesamum etc. are some of the disease management practices recorded in the book.
- (iii) Symptoms of plant diseases are cited in other ancient Indian literatures viz. *Jataka* of Buddhism, *Raghuvamsha* of Kalidas etc.
- (iv) The Europeans started systemic study of fungi in India during 19th century. They collected the fungi and sent to the laboratory in Europe for identification. D.D. Cunningham and A. Barclay, during 1850-1875, started identification of fungi in India itself. Cunningham specially studied on rusts and smuts. K.R. Kirtikar was credited as the first Indian scientist for collection and identification of fungi in India.
- (v) Edwin John Butler started the systemic study on Indian fungi and the diseases caused by them. This Imperial Mycologist came to India in 1901 and initiated the works on fungi at Imperial Agricultural Research Institute established by the British Government of Pusa (Bihar). The first and most classic book in the field of plant pathology of India i.e. *Fungi and Diseases in Plants* was written by him based on the exhaustive study on Indian fungi. He left India in 1920 and joined as the first Director of Imperial Mycological Institute in England. He is regarded as the Father of Indian Plant Pathology.
- (vi) Jahangir Ferdunji Dastur (1886-1971), a colleague of Butler, was the first Indian plant pathologists to made detail study of fungi and plant diseases. He specially studied the diseases of potato and castor caused by genus *Phytophthora* and established the species *P. parasitica* from castor in 1913. In recognition of his command in Plant Pathology, he was promoted to the Imperial Agricultural Science in 1919.
- (vii) G.S. Kulkarni, a student of Butler, generated detail information on downy mildew and smut of jowar and bajra. Another student S.L. Ajrekar studied wilt disease of cotton, sugarcane smut and ergot of jowar.
- (viii) Karam Chand Mehta (1894-1950) of Agra had contributed a lot to Plant Pathology of India. He first joined Agricultural College as a demonstrator at Kanpur. His outstanding contribution in the discovery of the life cycle of stem rust of wheat in India and reported that barberry, an alternate host, does not play any role in perpetuation of the rust fungus in India. He published two monographs entitled “Further Studies on Cereal Rust in India” Part I (1940) and Part II (1952) and also established three laboratories for rust works at Agra, Almora and Shimla.
- (ix) Raghbir Prasad (1907-1992) trained under K.C. Mehta, contributed to the identification of physiological races of cereal rusts and life cycle of linseed rust. Subsequently, L.M. Joshi at IARI conclusively studied various aspects of wheat rusts viz., chief foci of infection of rusts, dissemination of rust pathogens in India. Later on S. Nagarajan and L.M. Joshi developed most useful mathematical models in 1978 to predict appearance of stem and leaf rust of wheat.

- (x) Manoranjan Mitra was considered as one of the most critical plant pathologist worked on *Helminthosporium*. He first reported Karnal bunt of wheat in 1931 from Karnal in Haryana.
- (xi) B.B. Mundkur was the second mycologist trained under Butler and worked with Mehta and Mitra. He worked on control of cotton wilt by using resistant varieties and became successful in reducing yield loss in Maharashtra. His significant contribution is the establishment of Indian Phytopathological Society (IPS) in 1948 with its journal *Indian Phytopathology*. In the same year, he published a text book *Fungi and Plant Diseases* which was the second book of Plant Pathology after the classic book of Butler.
- (xii) S.R. Bose was taxonomist, mainly worked on the classification of Polyporaceae and isolated “polyporin” from *Polyporus*.
- (xiii) Notable contribution in the field of Mycology was made by M.J. Thirumalachar (1914-1999). He created 20 new genera and 300 new species of fungi, monographed genera of Uredinales of the world and Ustilaginales of India. Similarly many Hyphomycetes particularly *Fusarium* were elaborated by C.V. Subramanian in 1971.
- (xiv) Works on fundamental plant pathology, especially the biochemistry of host-parasite relationship were started at Lucknow and Madras (Chennai) lead by Sachindra Nath Dasgupta (1904-1990) and T.S. Sadasivan (1913-2001), respectively. Dr. Dasgupta initiated the works on leather mycology, paper pulp mycology and predacious fungi. Dr. Sadasivan’s school developed the concept of vivotoxin and reported the production of fusaric acid by *Fusarium vasinfectum* that causes wilt diseases in cotton.
- (xv) T.S. Ramakrishnan, a mycologist to Madras Government cultivated ergot diseased rye for toxin production. He published two books entitled *Diseases of Millets* (1963) and *Diseases of Rice* (1971). Renowned plant pathologists viz., G Rangaswami and R. Ramakrishnan were his students.
- (xvi) Plant Bacteriology in India got a shape with the effort of Makanji Kalyanji Patel (1899-1967). He established a school of Plant Bacteriology at College of Agriculture, Pune and first described a new species *Xanthomonas campestris* pv. *uppali* in 1948 from the host *Ipomea muricata*. He described more than 30 bacterial diseases from India. Other scientists viz., V.P. Bhide and G. Rangaswami also contributed their pioneering works to the phytobacteriology of India. D.N. Srivastava (1925-2000) is mostly remembered for his tremendous contribution on bacterial blight of rice. M.K. Hingorani reported about the complex nature of *tundu* disease of wheat caused by a bacterium and a nematode in 1952 and also he confirmed the causal agent of ring disease of potato as *Pseudomonas* (=*Ralstonia*) *solanacearum*. J.P. Verma (1939-2005) contributed many valuable findings on bacterial blight disease of cotton.
- (xvii) Plant virus research in India was started particularly at IARI, New Delhi under the leadership of R.S. Vasudeva (1905-1987), S.P. Raychaudhury (1916-2005) and Anupam Varma. Considering the importance of plant viral diseases, IARI established some Regional Research Stations at Shimla for temperate fruits (1952), at Pune for fruits and vegetables (1952) and at Kalimpong (West Bengal) for large cadamom,

citrus and other crops in north-eastern sub-Himalayan mountain (1956). Y.L. Nene's contributions have been well remembered particularly the viral diseases of pulses and the 'Khaira' disease of rice caused by Zinc deficiency. He wrote the book "Fungicides in Plant Disease Control".

(xviii) Teaching of plant pathology as a course was started at University of Calcutta, Bombay and Madras in 1857 where only fungal taxonomy was emphasized. But plant pathology as a university science was started in 1930 at University of Allahabad, Lucknow and Madras. Of which, perhaps University of Madras was first to introduce plant pathology as a course. Agra University had introduced one post-graduate programme in plant pathology in Govt. Agricultural College, Kanpur in 1945. The organized teaching in Mycology and Plant Pathology was began as a part of agricultural science under the banner of Indian Agricultural Research Institute. The subject received due importance and teaching of its supporting courses viz. mycology, bacteriology, virology and nematology in both under- and post-graduate programmes of Agriculture was taken up regularly after the establishment of Agricultural Universities in different states of India in 1960. At present, most of the courses related to plant pathology have been revised and added molecular plant pathology by keeping pace with the advancement in the science.

Parasitism and Pathogenesis

An organism which lives in or on other living organisms and derives its nutrients from the latter is called *parasite*. The relationship between a parasite and its hosts is known as parasitism. Many fungi and most bacteria grow on a non-living substrate within a living plant. The organism of this type of mode of nutrition is called *saprophyte*. Based on the different types of modes or nature of nutrition, the relationship between the host and parasite or saprophyte is termed in many ways viz., obligate parasite (biotroph), obligate saprophyte, facultative parasite, facultative saprophyte, hemibiotroph and necrotroph (perthotrophs or perthophyte).

Parasitism in cultivated crops is common phenomenon. Any agent that can cause suffering or damage or disease is called a *pathogen*. In plant pathology, the term 'pathogen' is usually used to the living or infectious organisms. The ability of a pathogen or parasite to cause disease is known as *pathogenicity*.

It is obvious that a plant becomes diseased when it is attacked by a pathogen or parasite. The ultimate condition i.e. disease occurs by passing through some distinct events. Thus, the genesis or chain of events or stages of disease development are called *pathogenesis*. This is also called as *disease cycle*. The events that occur in specific order are namely inoculation, penetration, establishment of infection, invasion or colonization, growth and reproduction, dissemination and survival of the pathogen (over wintering or over summering in absence of the host). The events will continue to repeat in the same order in presence of both the host and pathogen/parasite that may lead to severe disease condition.

Koch's Postulates

Robert Koch (1884-1890) forwarded four essential procedural steps called postulates for correct diagnosis of a disease and its actual causal agent. The postulates are:

1. Recognition: The pathogens must be found associated with the disease in the diseased plant. The symptom of the disease should be recorded.

2. Isolation: The pathogen should be isolated, grown in pure culture in artificial media. The cultural characteristics of the pathogen should be noted.
3. Inoculation: The pathogen of pure culture must be inoculated on healthy plant of same species/variety. It must be able to reproduce disease symptoms on the inoculated plant identical to step 1.
4. Re-isolation: The pathogen must be isolated from the inoculated plant in culture media. Its cultural characteristics should be similar to those noted in step 2 (This step was added by E.F. Smith).

If all the postulates are proved true, then the isolated pathogen is identified as the actual causal organism responsible for the disease.

Effect of pathogen on the plants

During the course of pathogenesis, normal activities of the infected host plant undergo malfunction. Consequently, morphological and physiological changes occur.

A. Morphological or structural changes: Physiological malfunctioning of the host cells causes disturbances in chemical reaction which ultimately lead to some structural changes viz., overgrowth, phyllody, sterile flowers, hairy roots, witches broom, bunchy top, crown gall, root knot, leaf curling, rolling, puckering etc.

B. Physiological changes:

- i. Disintegration of the tissues by the enzymes of the pathogen.
- ii. Effect on the growth of the host plant due to growth regulators produced by the pathogen or by the host under the influence of the pathogen.
- iii. Effect on uptake and translocation of water and nutrients.
- iv. Abnormality in respiration of the host tissues due to disturbed permeability of cell membrane and enzyme system associated with respiration.
- v. Impairing the phenomenon of photosynthesis due to loss of chlorophyll and destruction of leaf tissue.
- vi. Effect on the process of translation and transcription.
- vii. Overall reproduction system of the host.

Symptoms of Plant Diseases

A visible or detectable abnormality expressed on the plant as a result of disease or disorder is called *symptom*. The totality of symptoms is collectively called as *syndrome* while the pathogen or its parts or products seen on the affected parts of a host plant is called *sign*. Different types of disease symptoms are cited below:

Necrosis: It indicates the death of cells, tissues and organs resulting from infection by pathogen. Necrotic symptoms include spots, blights, burn, canker, streaks, stripes, damping-off, rot etc.

Wilt: Withering and drooping of a plant starting from some leaves to growing tip occurs suddenly or gradually. Wilting takes place due to blockage in the translocation system caused by the pathogen.

Die-back: Drying of plant organs such as stem or branches which starts from the tip and progresses gradually towards the main stem or trunk is called die-back or wither tip.

Mildew: White, grey or brown coloured superficial growth of the pathogen on the host surface is called mildew.

Rusts: Numerous small pustules growing out through host epidermis which gives rusty (rust formation on iron) appearance of the affected parts.

Smuts: Charcoal-like and black or purplish-black dust like masses developed on the affected plant parts, mostly on floral organs and inflorescens are called smut.

Blotch: A large area of discolouration of a leaf, fruit etc. giving a blotchy appearance.

White blisters: Numerous white coloured blister-like ruptures are surfaced on the host epidermis that forms powdery masses of spores of fungi. They are called white blisters or white rust.

Colour change: It denotes conversion of green pigment of leaves into other colours mostly to yellow colour, in patches or covering the entire leaves. (i) *Etiolation*: Yellowing due to lack of light, (ii) *Chlorosis*: Yellowing due to infection viruses, bacteria, fungi, low temperature lack of iron etc. (iii) *Albino*: Lack of any pigment and turned into white or bleached (iv) *Chromosis*: Red, purple or orange pigmentation due to physiological orders etc.

Exudation: Such symptom is commonly found in bacterial diseases when masses of bacterial cells ooze out to the surface of affected plant parts and form some drops or smear, it is called exudation. This exudation forms a crust on the host surface after drying.

Overgrowth: Excessive growth of the plant parts due to infection by pathogens. Overgrowth takes place by two processes (i) *Hyperplasia*: abnormal increase in size due to excessively more cell division (ii) *Hypertrophy*: abnormal increase in size or shape due to excessive enlargement of the size of cell of a particular tissue.

Atrophy: It is known as hypoplasia or dwarfing which is resulted from the inhibition of growth due to reduction in cell division or cell size.

Sclerotia: These are dark and hard structures of various shaped composed of dormant mycelia of some fungi. Sometimes, sclerotia are developed on the affected parts of the plant. Presence of sclerotia on the host surface is specifically called a sign of disease rather than symptom.

Development of epidemics

Sudden outbreak of a disease within a relatively short period covering a large area and affecting many individuals in a population is called *epidemic*. Although, this term was originally designated to the human diseases, now applied in the diseases of animals, poultry, plants etc. Epidemic form of plant diseases is called as *epiphytotics*.

For a disease to occur, coincidence of three parameters of disease triangle is essential, namely, the vulnerable host, virulent pathogen and favourable environment. Under such circumstances, the pathogen not only completes its life cycle but also undergoes repeated generations. Then an epidemic develops only when few repeated generations are completed by the pathogen on the same host. As each generation or cycle of the pathogen takes a few days for completion, the fourth parameter i.e. time factor (forms a disease tetrahedron or disease pyramid) is also involved in epidemic build up. In other words, epidemic growth is both temporal (pertaining to time) and a spatial (relating to space or area) process. The initial stages of an epidemic growth curve have a lag phase, when the incubation period is longer, inoculum load is weak and prevalent environmental conditions are unfavourable. Subsequently, when the conducive conditions occur, the growth of the disease is rapid and the severity of the epidemic explodes like a time bomb. Later, severity declines either due to unfavourable weather or crop maturity or both.

Plant Disease Management

The word 'control' is a complete term where permanent 'control' of a disease is rarely achieved whereas, 'management' of a disease is a continuous process and is more practical in influencing adverse affect caused by a disease. Disease management requires a detail understanding of all aspects of crop production, economics, environmental, cultural, genetics and epidemiological information upon which the management decisions are made.

A. Principles of plant disease management: There is six basic concept or principles or objectives lying under plant disease management.

1. **Avoidance of the pathogen:** Occurrence of a disease can be avoided by planting/sowing a crop at times when, or in areas where, inoculum remain ineffective/inactive due to environmental conditions, or is rare or absent.
2. **Exclusion of the pathogen:** This can be achieved by preventing the inoculum from entering or establishing in a field or area when it does not exist. Legislative measures like quarantine regulations are needed to be strictly applied to prevent spread of a disease.
3. **Eradication of the pathogen:** It includes reducing, inactivating, eliminating or destroying inoculum at the source, either form a region or from an individual plant (rouging) in which it is already established.
4. **Protection of the host:** Host plants can be protected by creating a toxin barrier on the host surface by the application of chemicals.
5. **Disease resistance:** Preventing infection or reducing the effect of infection of the pathogen through the use of resistance host which is developed by genetic manipulation or by chemotherapy.
6. **Therapy:** Reducing severity of a disease in an infected individual.

The first five principles are prophylactic (preventive) procedure and the last one is curative.

B. Methods of plant disease management

1. Avoidance of the pathogen:

- i. Choice of geographical area
- ii. Selection of a field
- iii. Adjustment of time of sowing

- iv. Use of disease escaping varieties
- v. Use of pathogen-free seed and planting material
- vi. Modification of cultural practices

2. Exclusion of inoculum of the pathogen

- i. Treatment of seed and plating materials
- ii. Inspection and certification
- iii. Quarantine regulations
- iv. Eradication of insect vector

3. Eradication of the pathogen

- i. Biological control of plant pathogens
- ii. Eradication of alternate and collateral hosts
- iii. Cultural methods:
 - a. Crop rotation
 - b. Sanitation of field by destroying/burning crop debris
 - c. Removal and destruction of diseased plants or plant parts
 - d. Rouging
- iv. Heat and chemical treatment of diseased plants
- v. Soil treatment: by use of chemicals, heat energy, flooding and fallowing

4. Protection of the host

- i. Chemical control: application of chemicals (fungicides, antibiotics) by seed treatment, dusting and spraying
- ii. Chemical control of insect vectors
- iii. Modifications of environment
- iv. Modification of host nutrition

5. Disease resistance

Use of resistant varieties: Development of resistance in host is done by

- i. Selection and hybridization for disease resistance
- ii. Chemotherapy
- iii. Host nutrition
- iv. Genetic engineering, tissue culture

6. Therapy

Therapy of diseased plants can be done by

- i. Chemotherapy
- ii. Heat therapy
- iii. Tree-surgery

Fungi

The term fungus (plural fungi) includes eukaryotic, spore-bearing, achlorophyllous, organisms that generally reproduce sexually and asexually, and whose usually filamentous, branched somatic structures are typically surrounded by cell walls containing chitin or cellulose, or both of these substances, together with many other complex organic molecules.

General morphology, characters and somatic structures of fungi

The thallus: Thallus is a growth form lacking differentiation into root, stem and leaves. In fungi, it is known as somatic (soma= body) phase. It may be plasmodial, unicellular, pseudoplasmodial or mycelial. A filamentous structure of fungal body composed of multicells is known as mycelium (pl. mycelia) and a fragment (unit) of mycelium is called hypha (pl. hyphae i.e. web). Hyphae or mycelia may be septate (having cross wall in the filament) or aseptate (without cross wall or septum).

Branching habit of mycelium: Dichotomous, sympodial, lateral, opposite, verticilliate, monopodial etc.

Other somatic structures: Rhizoides (rootlike), appressorium (pl. appressoria), haustorium (pl. haustoria), hyphopodium (pl. hyphopodia).

Hyphal aggregations and tissues: During certain stages of life cycle, fungal mycelia become organized loosely or compactly that form some structures called *plectenchyma* (i.e. woven tissue). Its two general types are known as *prosenchyma* (i.e. approaching a tissue) and *pseudoparenchyma* (a type of plant tissue). These two types compose various other somatic and reproductive structures like *stroma* (mattress), *sclerotium* (hard structure) and *rhizomorph* (root shaped).

Reproduction in fungi: Fungi reproduce by three processes viz., (A) Vegetative, (B) Asexual and (C) Sexual reproduction.

Vegetative reproduction

- a. Fragmentation
- b. Fission
- c. Budding
- d. Sclerotium
- e. Rhizomorph
- f. Chlamydospores
- g. Oidia (small egg)

Asexual reproduction

- a. **Exogenous:** The spores (reproductive units) borne at the tip or outside the vegetative structure called conidia (sing. conidium i.e. dust). Two types of conidia are thallosepores and conidiospores. The latter has got three types viz., Blastospores, Aleuriospores, and Phialospores. The bearing structure is called conidiophore (phore=bearer). Generally, conidia are developed on a simple (without branch) tubular conidiophore. Some other types of conidia bearing structures are phialids (small bottle type), synnema, coremia, acervulus (heap), sporodochia, pycnidia and sori (sing. sorus) or pustule.
- b. **Endogenous:** The spores produced in sporangia (sing. sporangium; vessel or container) and hence called sporangiospores. Sporangiospores are of two types viz. (i) plasmodiospores or zoospores or swarm spores which are motile due to having flagella and (ii) aplanospores which are non-motile due to lacking flagella.

Sexual reproduction

The sexual reproduction takes place by fusion of two compatible haploid nuclei, usually the gametes. There are two distinct fungal species

- a. **Monoecious or hermaphroditic:** they are bisexual having both sex organs on one thallus (homothallic).
- b. **Dioecious:** they are unisexual having either male or female sex organs on one thallus (heterothallic)

Four distinct phases of sexual reproduction are: somatogamy, plasmogamy, karyogamy and meiosis. These phases occur by any one of the following five general methods of sexual reproduction,

- i. Gametic copulation – (a) Isogamy and (b) Anisogamy
- ii. Gametangial contact
- iii. Gametangial copulation
- iv. Spermatization
- v. Somatogamy (Anastomosis)

Classification of Fungi, Taxonomy and Nomenclature

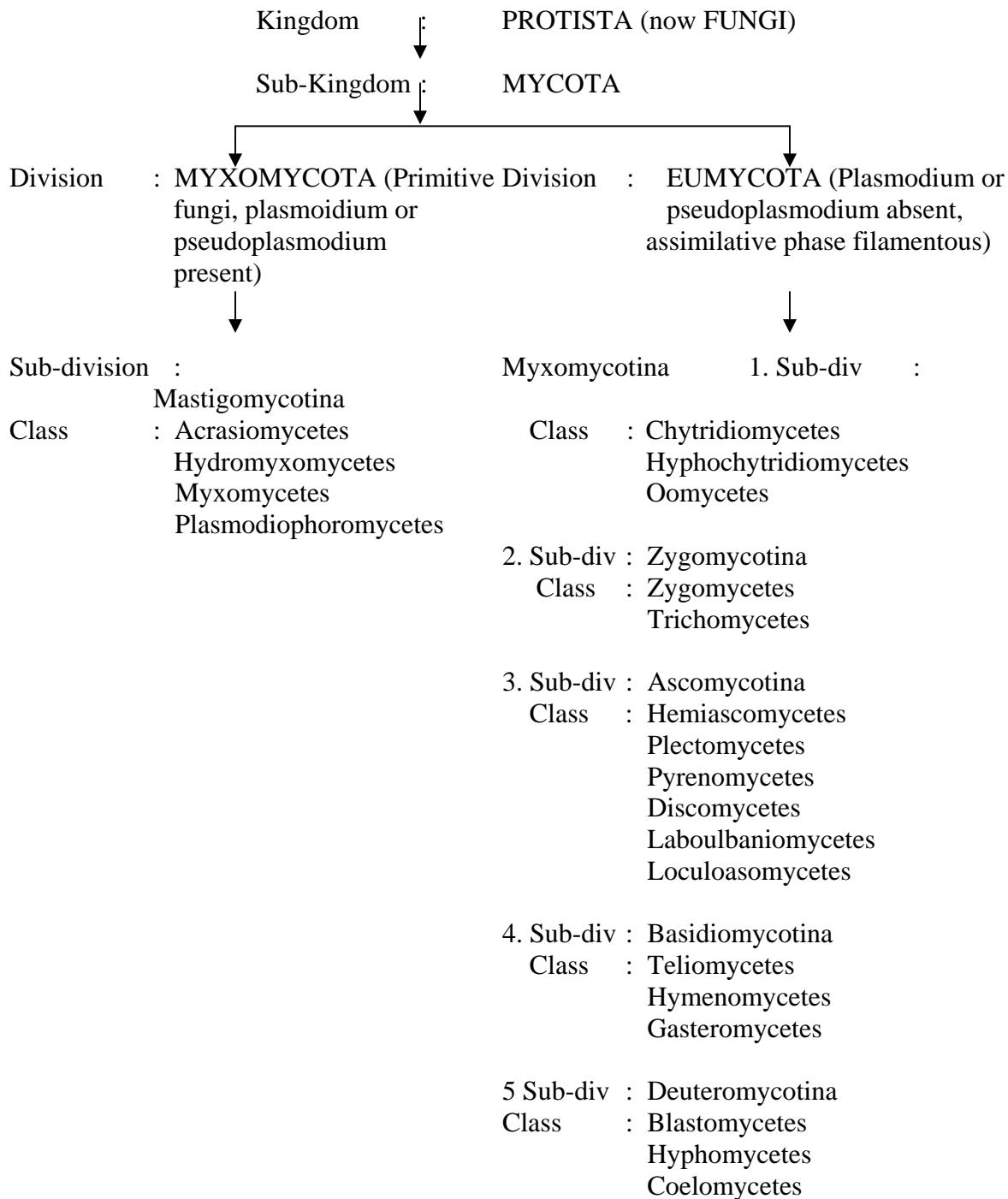
A. Taxonomy and units of Classification:

Super kingdom	- Eukaryonta
Kingdom	- Protista (now Fungi)
Sub-kingdom	- Mycota
Division	- mycota (suffix)
Sub-division	- mycotina (suffix)
Class	- mycetes (suffix)
Sub-class	- mycetidae (suffix)
Order	- ales (suffix)
Family	- aceae (suffix)
Genus	-
Species	-

Suffix are used or added to the scientific names of a taxon. A taxon (pl. taxa) is a category in the classification system. Whittaker (1969) provided five kingdom system viz., Monera, Protista, Plantae, Animalia and Fungi, and thus Fungi is separated from Protista on the basis of nutrition pattern.

B. Various classifications

Classification of fungi was given by various authors viz. Gwynne-Vaughan and Barnes (1927), Martin (1931, 1941), E.A. Bessey (1950). C.J. Alexopoulos (1962) etc. The classification forwarded by Ainsworth (1966 and 1972) is most widely accepted that has been given below:



Nomenclature

Naming of fungi and their classification fall under the rule of *International Code for Botanical Nomenclature*. The scientific name of an organism follows the pattern of binomial (bi = two+ nomen = name) nomenclature system, which is composed of two words. The first word designates the genus and the genus name is always capitalized. The second word designates the species and its name is not capitalized. Binomials when written are underlined and when printed italicized. Modification or updating, if any, in the nomenclature is done by a Committee for Fungal Nomenclature at each International Botanical Congress held at every four years interval.

Study of Selected Genera

(1) *Plasmodiophora* Woron.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Myxomycota
Sub-division	Myxomycotina
Class	Plasmodiophoromycetes
Order	Plasmodiophorales
Family	Plasmodiophoraceae
Genus	<i>Plasmodiophora</i>

The genus is an obligate parasite and causes important diseases such as club-rot of brassicas.

Resting spore: hyaline, spherical upto 4 μ in diameter, germinate to produce single anteriorly biflagellate primary zoospores.

Zoospores : a naked uninucleate protoplast, active, moving by irregular jerks and then comes in contact with root hair and become amoeboid, penetrate the cell wall and form a thallus in the host cell lumen.

Plasmodium: zygote and young plasmodia unite to form larger plasmodia found in cortical cells and later in various root and stem tissue, always intracellular, number of nuclei increases as it enlarges and occupies the entire lumen of an abnormally large host cell, in the late stage, cleavage takes place around each nucleus in the plasmodium and develop into resting spores, spores free from each other, held together by the host cell wall, until decomposed in the soil by secondary organisms.

(2) *Spongospora* (Waller.) Lagerheim

Kingdom	Protista
Sub-kingdom	Mycota
Division	Myxomycota
Sub-division	Myxomycotina
Class	Plasmodiophoromycetes
Order	Plasmodiophorales
Family	Plasmodiophoraceae
Genus	<i>Spongospora</i>

The genus has got limited host range of crop plants. It causes important disease like powdery scab in potato and acts as a vector of potato-mop-top virus disease.

Resting spore: germinate by release of biflagellate zoospores, which penetrates root hairs, thallus enlarge, become multinucleate and on germination form zoosporangia a thick walled, round to oval body.

Zoospores: protoplasm of zoosporangium divides to form upto 50 secondary zoospores, discharge through an opening common to zoosporangial wall and host cell wall, biflagellate of unequal length, zoospores from zoosporangia may reinfect and produce another zoosporangium, this stage is repeated as long as young roots are available and conditions are favourable.

Plasmodium: amoeboid stage of fused secondary zoospores form intracellularly plasmodium, invaded cells enlarge and divide into several infected cells, wart like structure is formed by abnormal cell growth and cell division, plasmodium gives rise to spore balls (19-85 μ) which consist of spongy mass with irregular internal channels, form yellow brown dust in mature sori, spore balls contain many individual cells, each constituting an individual uninucleate resting spore.

(3) *Synchytrium* deBary & Woron.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Chytridiomycetes
Order	Chytridiales
Family	Synchytriaceae
Genus	<i>Synchytrium</i>

The genus causes important wart disease of potato. The pathogen is widespread in many countries and on many hosts.

Thallus: developing into either a group of zoosporangia or a resting spores, initial thallus functioning as sorus and segmenting directly into a number of zoosporangia or gametangia, or as an evanescent prosorus from which the contents emerge through a pore and form an attached vesicular sporangial or gametangial sorus outside of the initial thallus but within the infected host cell, or developing into a resting spore.

Zoosporangia and Gametangia: variously shaped but predominantly polyhedral with hyaline wall and red, orange, yellow, reddish yellow, lemon coloured, grey or hyaline granular contents, dehiscing by a tear, cleft or papilla.

Zoospores and Gametes: ovoid, ellipsoid, solid oblong, spherical or pyriform, usually with 1 and sometimes 2 conspicuous, refringent globules, and a single posterior, whiplash flagellum.

Resting spores: formed by fusion of isogametes, with the resulting zygotes infecting the host and developing into diploid resting spores; exospores thick, smooth, rough or ridged, hyaline, amber coloured, reddish brown or light or dark brown; endospores relatively thin and hyaline, content variously coloured with a few to numerous refringent globules, functioning as a sporangium or a prosorus in germination.

(4) *Physoderma* Wallroth

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Chytridiomycetes
Order	Chytridiales
Family	Physodermataceae
Genus	<i>Physoderma</i>

Among all the chytridiomycete, *P. maydis* only causes a disease of some importance in overground parts of plants, e.g. brown spot disease of corn.

Rhizomycelium: endobiotic, tenuous portions filamentous, delicate, fine or comparatively coarse, intercalary, enlargements, oval, elliptical, subspherical, broadly spindle shaped, turbinate and occasionally irregular, usually septate, bi or multicellular.

Rhizoides: haustoria arising from most portions of the rhizomycelium, often reduced, digitate.

Ephemeral zoosporangia: usually epibiotic, gregarious, sessile, pyriform, oval elongate, slipper shaped, irregular, sunken and deeply lobed, sometimes star shaped and angular, dehiscing by deliquescence of apical papilla, proliferating, subtended by a small endobiotic apophysis, richly branched and bushy, or reduced and digitate rhizoids.

Zoospores: from ephemeral sporangia usually smaller than those from resting sporangia, ellipsoidal oval, almost spherical, usually tapering posteriorly, with a conspicuous, eccentric, refractive globule.

Resting sporangia: formed on endobiotic rhizomycelium, terminal or intercalary, ellipsoidal, oval truncate, sub-hemispherical and flattened on one surface, sometimes slightly irregular, smooth or grooved; amber, light to dark brown, usually with thick epispor and thin endospore, contents coarsely granular or with one to several, large refractive globules, with or without an encircling ring of blunt, digitate, haustoria, germinating by an endosporangium which pushes up an oval or a circular, saucer shaped lid, or irregularly cracks the epispor; endosporium emerging partly, to emit zoospores by deliquescence of an apical papilla.

Sexual organ: Unknown, doubtful or lacking

(5) ***Pythium*** Pringsheim

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Pythiaceae
Genus	<i>Pythium</i>

Pythium spp. are common as soil inhabitants with long survival rates. They generally parasites on wide host range and mainly causing both pre and post-emergence damping-off; in general root rots of young plants.

Mycelium: well developed, much branched or unbranched hyphae, occasionally bearing appressoria and chlamydospores.

Zoosporangium: either entirely filamentous and undifferentiated from the vegetative hyphae, simple or branched, acrogenous or intercalary, or consisting of a series of basal, complex lobulations and a filamentous discharge tube or a well defined sphaeroidal structure sharply distinct from its supporting hypha, an acrogenous, intercalary or laterally sessile, with a emission tube of variable length, sometimes internally proliferous.

Zoospores: somewhat reniform, each containing a single vacuole and with two oppositely directed flagella of equal length, emerging from a shallow, longitudinal groove, expelled from the sporangium as an undifferentiated mass into a delicate vesicle produced by the tip of the discharge tube and where cleavage and maturation take place, capable of repeated emergence before finally encysting and germinating; probably always monoecious.

Oogonia: terminal or intercalary, spherical or sub-spherical when terminal, ellipsoidal to limoniform when intercalary, smooth walled or variously echinulated, for the most part forming a single oospore with or without conspicuous periplasm.

Antheridia: none or one to several, hyphogynous, monoclinous or dichlinous, allantoid, clavate, globose, sub or trumpet shaped, terminal or intercalary, borne on a short or long stalk, or sessile, usually one to four to an oogonium, forming a distinct fertilization tube.

Oospores: usually borne singly within the oogonium, pleuratic or apleurotic, wall smooth or reticulate, thin or inspissate, the granular protoplasm usually bearing a conspicuous reserve, globule and a lateral refringement body; upon germination forming one or several germtubes or zoospores.

(6) *Phytophthora* deBary

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Pythiaceae
Genus	<i>Phytophthora</i>

Phytophthora is one of the most important plant pathogenic genera. Members of this genus frequently cause root rot and pre and post seedling diseases and are more often specialized and destructive plant pathogens.

Mycelium: white in mass, in host often with haustoria.

Hyphae: 3-8 μ , irregularly swollen undulate, sometimes with characteristic swellings, initial branching at right angles to parent hyphae and often swollen for a short distance.

Chlamydospores: Thick walled secondary spores, usually spherical, intercalary, sometimes terminal, wall smooth, upto 2 μ thick, hyaline.

Sporangiospores: usually undifferentiated, branching sympodial or irregular and from below the sporangium or from within an empty one.

Sporangia: usually terminal, single on long hyphae in sympodia or within an evacuated sporangium; ellipsoid, ovoid, obpyriform, apex differentiated by an internal hyaline, thickening of the inner wall and sometimes protruding to form a papilla, wall smooth upto 2 μ thick, non caducous or shed with a pedical, germination by zoospores emerging individually through apex or by germtube.

Zoospores: hyaline, ovoid to phaseoliform, biflagellate, interiorly directed tinsel (shorter) and posteriorly directed whiplash (longer), when mortality ceases the spherical cyst may show repetetional emergence but not diplanetism.

Oogonium: usually terminal, spherical or tapering to the stalk, delimited by a thick septum, wall hyaline, thin, becoming thicker and often yellow to brown, mostly smooth occasionally tuberculate or reticulate.

Antheridium: usually single, monoclinous or diclinous, spherical oval, clavate or short cylindrical, often angular, amphigynous, or paragynous.

Oospores: single more or less filling oogonium; spherical, smooth, hyaline, outer wall very thin, inner wall 0.5-6 μ thick, when mature with large central globule.

(7) ***Sclerophthora*** Thirum., Shaw and Naras.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Pythiaceae
Genus	<i>Sclerophthora</i>

Sclerophthora spp. are restricted to Gramineae particularly on leaves and inflorescences and cause the distinctive symptoms of chlorotic streaking, stunting, shedding, proliferation and hypertrophy.

Mycelium: Hyaline, coenocytic, sporangial stage like *Phytophthora*.

Sporangiophores: hyphoid, very little differentiated from the hyphae within the host, simple or sympodially and successively branched.

Sporangia: large, limoniform or obpyriform, apically poroid, borne singly at the apices of the sporangiophores, germinating in water by division of the cell contents into bicillate zoospores.

Oogonia: wall thickened and confluent with the wall of oospores.

Oospores: germination indirect by sporangial formation.

(8) ***Sclerospora*** Schroet.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Peronosporaceae
Genus	<i>Sclerospora</i>

The genus has many species which are important obligate pathogen of cereals attacking leaves, stems and inflorescence, germination of the oospores is direct by means of germ tube.

Mycelium: intercellular, bearing small, usually knob-like unbranched haustoria.

Sporangio-conidiophores: typically stout composed of a main trunk and a compact group of rather short apical branches which are one to several times divided, branching dichotomous to indefinite.

Sporangio-conidia: germinate by one or more germtubes or by zoospores.

Oospores: wall being confluent with that of the oogonium and by the stout conidiophore with heavy branches clustered at the apex.

(9) *Peronospora* Corda.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Peronosporaceae
Genus	<i>Peronospora</i>

The genus is an obligate parasite and causes downy mildew disease in crucifers.

Mycelium: thick, coenocytic, intercellular, branched, lobed with coarse haustoria.

Conidiophores: emerge through stomata, singly or in clusters, slender, sometimes with bulbous or twisted base, unbranched upto 2/3 of its length, branching dichotomously 2-7 times, at acute angles, sterigmata taper to thin point, swell into sac and form single conidium at the tip.

Conidia: oval, ellipsoidal, hyaline, 24-27 x 15-20 μm , readily fall-off and germinate by lateral germtube.

Sex organs: oogonium spherical, hyaline, both oogonium and antheridia first multinucleate but soon the other nuclei pass to periplasm and degenerate, one male and one female nucleus remain functional.

Oospores: produced in host tissue in late stage; globose 26-42 μm , pale yellow, enclosed in crest like folds formed by the periplasm.

(10) *Perenosclerospora* (Ito) Shirai and K. Hara

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Peronosporaceae
Genus	<i>Perenosclerospora</i>

Shaw (1970) erected *Perenosclerospora* as new genus attacking graminaceous hosts in the subtropic and tropics causing downy mildew disease particularly in maize, millets, sorghum and sugarcane. Infection takes place in newly germinated plants, sometimes directly from oospores present in the soil. The secondary infection occurs by air borne spores mostly before sunrise. The spread of disease is generally short distanced as conidiophores are extremely prone to desiccation.

Sporangiosphore-sporangia (Vegetative phase): primary aerial sporophore, comes out from host surface, 10 μm or more broad, usually 15-25 x 2-3 μm , dichotomously branched in the upper part, sporangia usually non-papillate, forming zoospores, oogonia

Oogonia: wall thick, rough or ornamented,

Oospore: plerotic

(11) *Albugo* (Pers) S.F. Gray

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Mastigomycotina
Class	Oomycetes
Order	Peronosporales
Family	Albuginaceae
Genus	<i>Albugo</i>

The genus causes white rust disease in many crops

Mycelium: intercellular, widespread, bearing simple, globose, intracellular haustoria.

Sori: subepidermal, later erumpent, forming white to cream, patches on all aerial parts of host.

Sporangiophores: crowded, clavate, hyaline; forming basipetal chains of sporangia, joined by colourless connective links.

Sporangia (Zoosporangia): all alike or terminal sporangium larger than the others, globose, elliptical, oblong cubical or truncated obovate, hyaline, wall smooth, equally thickened.

Sexual organs: anthredia and oogonia borne singly on short terminal or lateral mucelial branches within host tissue.

Oogonia: globose, differentiated into periplasm and oosphere.

Anthredia: small club shaped, arising near oogonia.

Oospores: thick walled, globose, epispires dark coloured, ornamented with warts, ridges or reticulations, germination by zoospores.

(12) *Taphrina* Fr.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Ascomycotina
Class	Hemiascomycetes

Order	Taphrinales
Family	Taphrinaceae
Genus	<i>Taphrina</i>

The spp. causes gall formation on leaves, stem and fruits. Hypertroph of infected tissues and deformed leaves and fruits occurs, blister-like leaf lesions, and witches brooms, occurs on temperate broad-leaved tree and stone fruits.

Mycelium: intercellular, sub-cuticular or within the epidermal wall, forming asci in subcuticular layer or a wall locule; overwintering in the form of blastospores derived from ascospores by budding, infection is by blastospores.

Asci: arise from rounded ascogenous cells, either by elongation of the ascogenous cell or by bursting out from the ascogenous cell wall. Budding of the ascospores to form blastospores may also occur within the ascus and continue after spore expulsion.

(13) *Erysiphae* Hedwig ex. Merat

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Ascomycotina
Class	Pyrenomycetes
Order	Erysiphales
Family	Erysiphaceae
Genus	<i>Erysiphe</i>

The fungi belonging to this group are obligate biotrophs that cause a major group of plant diseases commonly known as powdery mildews.

Ascospores (Cleistothecia): with simple, myceloid appendages but with several asci.

Conidiophores: on superficial hyphae with abundant conidia.

Conidia: borne in chains, base of the conidiophores straight or swollen.

Mycelium: superficial

(14) *Claviceps* Tul.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Ascomycotina
Class	Pyrenomycetes
Order	Clavicipitales
Family	Clavicipitaceae
Genus	<i>Claviceps</i>

The various species of genus *Claviceps* causes disease in plants known as ergot which is name for sclerotia. The sclerotia, which may contain toxic alkaloids produce disease in humans/animals known as ergotism.

Stromata: borne on a elongated black sclerotium.

Sclerotium: club shaped with globose heads, round to elliptical.

Perithecia: completely, sunk in the head.

Asci: unitunicate, cylindrical bearing ascospores.

Ascospores: thread like

(15) *Sclerotinia* Fuckel

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Ascomycotina
Class	Pyrenomycetes
Order	Helotiales
Family	Sclerotiniceae
Genus	<i>Sclerotinia</i>

Sclerotinia spp. are mostly soil inhabitant and cause many important diseases in crop plants.

Apothecia: arising from well defined tuberoid sclerotia.

Sclerotia: freed from the substrate at maturity or only loosely enclosed within it, rind black, medulla usually white.

Microconidia: borne in sporodochia, superficial or in cavities in the host.

Apothecia: brown, disk saucer shaped or flat, receptacle downy or scurfy.

Asci: 8 spored.

Ascospores: elliptical, inequilateral or very slightly reniform, hyaline, aseptate, often binucleate, usually uniseriate.

(16) *Puccinia* Persoon ex Persoon

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Uredinales
Family	Pucciniaceae
Genus	<i>Puccinia</i>

Puccinia spp. are causing rust diseases in many economically important crops and substantial losses in family Grammineae. This is the largest genus of rust fungi with 3-4 thousand spp.

Spermogonia: subepidermal

Aecidia: subepidermal in origin, aecidioid with a membranous peridium and catenulate spores or uredinoid with aecidiospores borne single or endophylloid with aecidioid sori but the spore germinating to form basidia.

Uredia: subepidermal, paraphysate or a paraphysate.

Urediospores: borne singly wall usually echinulate.

Teliosori: subepidermal, erumpent.

Teliospores: typically 2 celled, less commonly 1, or 3-4 celled, one pore in each cell, pedicels long or short, persistent or deciduous, wall coloured, basidia external, typically 4 celled.

(17) *Uromyces* (Link) Unger

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Uredinales
Family	Pucciniaceae
Genus	<i>Uromyces</i>

Responsible for causing rust disease in many crops. Largest genus after *Puccinia*.

Spermogonia: deeply embedded in the tissues of the host, flask shaped with conical mouth and ostiolar filaments and flexuous hyphae.

Aecidia: usually with an evident, generally cup shaped peridium

Aecidiospores: with indistinct pores.

Urediospores: formed singly on their pedicels, with several distinct pores, rarely accompanied by paraphyses.

Teliospores: aseptate on distinct pedicels, always with an apical, hyaline epiculus.

Basidiospores: flattened on one side or kidney shaped, autoecious or heteroecious in nature.

(18) *Melampsora* Castagne

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Uredinales
Family	Melampsoraceae
Genus	<i>Melampsora</i>

Responsible for causing rust in some commercial crops like flax (linseed) and castor.

Spermogonia: subcuticular or subepidermal, conical or hemispherical, without paraphyses but sometimes with flexuous hyphae.

Aecidia: coemoid usually foliicolous, without peridium or sometimes with peripheral hyphae like paraphyses which may unite to form a rudimentary peridium.

Aecidiospores: catenate, globoid, or elliposoid, with verrucose walls.

Uredia: subepidermal, pulverulent, with a thin, evanescent peridium, stalked.

Urediospores: borne single on pedicels, globoid or ellipsoid, with indistinct pores; with capitate or clavate paraphyses.

Tellia: subcuticular or subepidermal, forming crusts consisting of a single layer of spores.

Teliospores: single celled, adhering laterally with coloured walls forming a crust with one indistinct apical pore, germinating in spring.

Basidia: typically 4 celled, producing globoid, colourless or yellowish basidiospores.

(19) *Ustilago* (Pers.) Roussel

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Ustilaginales
Family	Ustilaginaceae
Genus	<i>Ustilago</i>

This is the largest genus causing smut diseases in family Gramineae.

Sori: borne in various parts of the host, forming dusty, dark, spore masses at maturity.

Spores: single, produced irregularly in fertile mycelial threads which later disappear through gelatinisation. Germination by septate promycelium producing infection threads or sporidia formed terminally and laterly near the septa, sporidia germinate in water to form infection hyphae or budding indefinitely in nutrient solutions.

(20) *Sporisorium* (=*Sphacelotheca*) de Bary

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Ustilaginales
Family	Ustilaginaceae
Genus	<i>Sphacelotheca</i>

Sporisorium spp. cause smut diseases in Gramineae family.

Sori: in the inflorescence, predominantly in the ovaries, covered with a definite pseudomembrane enclosing a dusty spore mass and a central columella; pseudomembrane later

flaking away, composed largely or entirely of definite sterile cells; hyaline or slightly tinted in nature, sometimes more or less firmly bound together.

Spores: free, single, developed in a somewhat centripetal manner, small to medium size, germination as in *Ustilago*.

(21) *Tolyposporium* Woron.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Ustilaginales
Family	Ustilaginaceae
Genus	<i>Tolyposporium</i>

The genus is responsible for causing smut in cereals and grasses.

Sori: in the inflorescence, usually in ovaries, forming a granular to agglutinated spore mass.

Spore balls: composed of numerous spores bound together by ridged folds or thickening of their outer walls known as sterile cells.

Spores: small to medium size, often with a reticulate aspect due to the characteristic folds or thickenings which bind them together in the balls. Germination by 3-4 celled promycelium with sporidia borne at the septa.

(22) *Tilletia* Tul.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Ustilaginales
Family	Tilletiaceae
Genus	<i>Tilletia</i>

The species mostly occurs on Gramineae and are important pathogens on temperate cereals and grasses.

Sori: mostly in the ovaries, occasionally in vegetative tissues, forming powdery to agglutinated spore masses, often foetid, emit foul odour due to trimethylamine.

Spores: single, formed from intercalary cells of a sporogenous mycelium or terminally on sporogenous hyphae, commonly encased in a hyaline or thin, gelatinoid sheath, comparatively large and regular, exhibiting a wide range in size, variously sculptured (commonly reticulate, cerebriform, verrucose, spiny, tuberculate or rarely smooth) pallid to opaque, germinating by a continuous promycelium, bearing terminal sporidia that usually fuse *in situ*, giving rise to

secondary sporidia; immature spores few to copious, similar in morphology to the mature spores but pigmented to a lesser degree; sterile cells, single, present in varying numbers, hyaline to tinted, smooth to granular, naked or sheathed, variously shaped.

(23) *Neovossia* (Mitra) Mundkur

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Basidiomycotina
Class	Teliomycetes
Order	Ustilaginales
Family	Tilletiaceae
Genus	<i>Neovossia</i>

Sori: mostly in grains and partially infected, containing black powdery mass of teliospores, in severely infected grains most of the seed tissues is converted into bunt spores, infected portion of seed is grey, later turns black, emit foul odour due to trimethylamine.

Spores: globose to subglobose, 22-49 μm in size, black, some spores bear hyphal appendages (apiculus), with curved spines and reticulation on the episore, spines covered with thin hyaline membrane, spores intermixed with globose to elongate, yellow to yellowish-brown, smooth, thick walled sterile cells.

(24) *Alternaria* Nees ex Fr.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hymomycetes
Order	Hymomycetales
Family	Dematiaceae
Genus	<i>Alternaria</i>

The genus causes economically important diseases in various crops, mostly as necrotic lesions on leaves, stems and fruits.

Colonies: effuse, usually grey, dark blackish brown or black.

Mycelium: immersed or particularly superficial, hyphae colourless, olivaceous brown or brown.

Conidiophores: macronematous, simple or irregularly and loosely branched, pale brown or brown, solitary or in fascicles.

Conidiogenous cells: integrated, terminal becoming intercalary, polytretic, sympodial or sometimes monotretic, cicatrised.

Conidia: catenate, solitary, dry, typically ovoid or obclavate, often rostrate, pale or mid-olivaceous brown to brown, smooth or verrucose, with transverse and frequently also oblique or longitudinal septa.

(25) ***Helminthosporium*** Link ex Fr.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hyphomycetes
Order	Hyphomycetales
Family	Dematiaceae
Genus	<i>Helminthosporium</i>

The economically important species occurring on Gramineae have been placed under Genus *Drechslera* which differs from *Helminthosporium* (Subramanian and Jain, 1966). Only few species cause diseases viz., silver scurf of Irish potato while rest are common on dead stems of herbaceous plants.

Colonies: effuse dark, hairy

Mycelium : immersed

Stroma: usually present, dark, often large

Conidiophores: macronematous, mononematous, unbranched, straight or flexuous, cylindrical or subulate, mid to very dark brown, smooth or occasionally verruculose, with small pores at the apex and laterally beneath the septa.

Conidiogenous cells: polytretic, integrated, terminal and intercalary, determinate, cylindrical.

Conidia: solitary, acropleurogenous, developing laterally often in verticils through very small pores beneath the septa whilst the tip of the conidiophore is actively growing, growth of conidiophore ceasing with the formation of terminal conidia, simple, usually obclavate, sometimes, rostrate, subhyaline to brown, smooth, pseudoseptate, frequently with a prominent dark brown to black scar at the base.

(26) ***Cercospora*** Fresenius

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hyphomycetes
Order	Hyphomycetales
Family	Dematiaceae
Genus	<i>Cercospora</i>

There are more than 2000 species but only few species causes the disease in economically important crops.

Colonies: effuse, grayish brown, tufted

Mycelium: mostly immersed

Stroma: often present but not large

Conidiophores: macronematous, mononematous, caespitose, straight or flexuous, sometimes geniculate, unbranched or rarely branched, olivaceous brown or brown, paler towards the apex, smooth.

Conidiogenous cells: integrated, terminal, polyblastic, sympodial, cylindrical, cicatrized, scars usually conspicuous.

Conidia: solitary, acropleurogenous, simple, obclavate or subulate, colourless or pale, pluriseptate, smooth.

(27) *Pyricularia* Sacc.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hymenomycetes
Order	Hymenomycetales
Family	Dematiaceae
Genus	<i>Pyricularia</i>

The *Pyricularia* spp. is mainly pathogenic to cereals and *P. oryzae* causes rice blast worldwide. Some species are host specific.

Colonies: effuse, thin, hairy, grey to greyish, brown or olivaceous brown

Mycelium: immersed

Chlamydospores: sometimes found in culture

Stroma : none

Setae and Hyphopodia : absent

Conidiophores: macronematous, mononematous, slender, thin walled, usually emerging singly or in small groups through stromata, mostly unbranched, straight or flexuous, geniculate towards the apex, pale brown, smooth.

Conidiogenous cells: polyblastic, integrated, terminal, sympodial, cylindrical, geniculate, denticulate, each dental cylindrical, thin walled, cut off usually by septum to form a separating cell.

Conidia: solitary, dry, acropleurogenous, simple, obpyriform, obturbinate or obclavate, hyaline to pale olivaceous brown, smooth, 1-3 (mostly 2) septate, hilum often protuberant.

(28) *Fusarium* Link ex Fr.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hyphomycetes
Order	Tubulariales
Family	Tubulariaceae
Genus	<i>Fusarium</i>

The genus is commonly associated with soil-borne diseases.

Macroconidia: are fusoid, one or more septate, with a foot cell bearing heel.

Microconidia: non-septate to one septate, ovoid to short cylindric, in short chains or more commonly in spore balls.

Chlamydospores: globose with a thick walled, intercalary, solitary, in chains or clumps, or terminal as short lateral branches. They may also be formed from cell of the macroconidia.

(29) *Rhizoctonia* DC. ex Fr.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Hyphomycetes
Order	Agonomycetales
Family	Agonomycetaceae
Genus	<i>Rhizoctonia</i>

Rhizoctonia species are mostly soil inhabitant. Disease symptoms caused are seed decay, damping off, stem lesion and canker, root rot, above ground rot, leaf blight and storage rot.

Colonies: colourless, rapidly become brown, aerial mycelium variable, sparsely branched hyphae are frequently present.

Sclerotia: irregular size and shape but of uniform structure, brown or black, more or less loosely packed.

Hyphae: cells of hyphae at advancing edge usually 5-12 μm wide and upto 250 μm long. Branches arise near distal end of cell, are constricted at point of origin and septate shortly above, cells multinucleate with conspicuous dolipore septa, the angle of branching approaches 90° and branches may arise at the various points along the cell length.

(30) *Sclerotium* Sacc.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota

Sub-division	Deuteromycotina
Class	Hyphomycetes
Order	Agonomycetales
Family	Agonomycetaceae
Genus	<i>Sclerotium</i>

Sclerotium is an unspecialized parasite, a soil inhabitant and with very wide host range in warm and wet areas.

Colonies: usually white with many mycelial strands in the aerial mycelium.

Sclerotia: develop on colony surface, nearly spherical, mostly 1-2 mm across, with smooth or shallow pitted shiny surface,

Hyphae: initially hyphal cell is usually 4.5-9 μm wide and upto 350 μm long with one or more clamp connections at septa.

(31) *Phyllosticta* Desm.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Coelomycetes
Order	Sphaeropsidales
Family	Sphaeropsidaceae
Genus	<i>Phyllosticta</i>

The genus should not be confused with *Phoma* which has aseptate conidia without a slim layer or an apical appendage and a different development of the conidium. Only few spp. are economically important to crops causing leaf spots.

Stroma: prosenchymatous or plectenchymatous, well developed in pure culture, often reduced or absent.

Pycnidia: globose, pyriform or tympaniform, separate or in small groups, embaded in a subepidermal stroma, uni or multilocular, ostiolate, wall prosenchymatous or pseudoparenchymatous, variable in thickness, not sharply delimited from the stroma, outer cells mostly dark and thick walled, inner cells hyaline, isodiametric, giving rise to conidiogenous cells.

Conidiogenous cells: short cylindrical or conical, forming blastoconidia in basipetal succession and abstracting them from a fixed locus with a broad base.

Conidia: aseptate, hyaline, globose, obovoidal, ellipsoidal or clavate, broadly rounded apically, flattened, surrounded by slime layer and a apical appendage, usually containing characteristic greenish guttules, generally 8-20 x 5-10 μm , often forming appresoria on germination.

(32) ***Phoma*** Sacc.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Coelomycetes
Order	Sphaeropsidales
Family	Sphaeropsidaceae
Genus	<i>Phoma</i>

Phoma spp. occur as family specialized pathogen but some are generally weak and plurivorous parasites, saprophytes and soil fungi.

Pycnidia: mostly glabrous but sometimes hairy, usually globose-subglobose or globose-ampulliform to obpyriform, separated or in small groups, usually subepidermal then erumpent with mostly one, but sometimes more with papillate openings (ostiole and porus), wall pseudoparenchymatous or prosenchymatous, the outer cells mostly dark and thick walled, the inner cells hyaline and more or less isodiametric.

Conidiogenous cells: are usually indistinguishable from the inner cells of the pycnidial wall but for a single aperture.

Conidia: hyaline or sometimes slightly coloured (yellow to pale brown), globose, ovoidal, ellipsoidal or clavate, mostly once or twice as long as wide, generally $2.5-10 \times 1-3.5 \mu\text{m}$, aspetate but secondary separation may occur resulting in 2 celled conidia.

(33) ***Colletotrichum*** Corda.

Kingdom	Protista
Sub-kingdom	Mycota
Division	Eumycota
Sub-division	Deuteromycotina
Class	Coelomycetes
Order	Melanconiales
Family	Melanconiaceae
Genus	<i>Colletotrichum</i>

The forms of *Colletotrichum* have a very wide range of behavioural patterns in nature, varying from saprophytes to specialized parasites with a narrow host range. The species generally survive for long periods on plant debris, in or on the soil.

Mycelium: immersed, branched, septate, hyaline to pale brown, intracellular

Acervuli: subcuticular, epidermal to subepidermal, septate or confluent, formed of hyaline or brown, thin or thick walled, pseudoparenchymatous.

Setae: present or absent, originating irregularly, from the pseudoparenchyma, more or less straight, unbranched, tapered to an acute or obtuse apex, brown, smooth, thick walled, septate.

Conidiophores: septate, branched at the base, hyaline to pale brown, smooth formed from upper cells of pseudoparenchyma.

Conidiogenous cells: enteroblastic, phialidic, discrete or incorporated on conidiophores, determinate, cylindrical, hyaline to pale brown, smooth, narrow, periclinal wall thickened, collarette, sometimes distinct.

Conidia: hyaline, aseptate, more or less guttulate, cylindrical, long clavate, falcate, fusiform or mucilaceous, on germination become pale brown, septate and form appressoria.

Bacteria

Bacteria (sing. bacterium) are simplest prokaryotic unicellular microorganisms having the common chemical composition of DNA, RNA and protein. They are highly adaptable and can survive extremes of temperatures, pH, oxygen tension, osmotic and atmospheric pressures, and hence found in almost all natural conditions.

Morphological characters: Being unicellular organism, bacteria may form groups of cells as filaments. They are either motile or non-motile and lack the definitely organized nucleus. Bacterial cell possess five shapes- (i) spherical (*Micrococcus*), (ii) rod-like /bacilliform (*E. coli*) and (iii) spiral-shaped (*Spirillum*) and (iv) curved-rod (*Vibrio*) and (v) club-shaped (*Clavibacter*). Motile cells are having long, whip-like flagella which may arise from one or both ends of the cell (polar) or from all over the cell (peritrichous). Based on flagellar arrangement bacteria is classified into 6 groups:

(i)	Monotrichous	-	single polar flagellum at one end (<i>Xanthomonas</i>)
(ii)	Amphitrichous	-	single polar flagellum at both ends (<i>Pseudomonas</i>)
(iii)	Cephalotrichous	-	several flagella at one end (<i>P. fluorescens</i>)
(iv)	Lophotrichous	-	several polar flagella at both ends (<i>Spirillum</i>)
(v)	Sub-polar	-	single sub-polar flagellum (<i>Agrobacterium</i>)
(vi)	Peritrichous	-	all over the cells (<i>Erwinia</i>)

Many bacteria have filamentous appendages called fimbriae or pili. The size of bacteria ranges from 1-5 μm and normal range of volume of a structural unit lies within 5-50 μm^3 .

Structurally, a bacterial cell can be divided into following 5 regions as follows:

i. **Surface appendages:** Flagella and pili

ii. **Surface adherents:** Capsules and slime layers. The capsule in the outer most layer and composed of polysaccharide or disaccharide and in some cases polypeptides. When polysaccharide is more fluid in consistency, it forms a gelatinous slime layer around the cell wall.

iii. **Cell wall:** It provides shape to the cell and protects underlying protoplasm having cytoplasm, chromatin, vacuoles, globules etc. The bacterial cell wall is made up of mucopeptide (murein). On the basis of two types of chemical composition of cell wall, bacteria are grouped into two as Gram +ve (85% or more mucopeptide and rest is simple polysaccharide) and Gram -ve (only 3-12% mucopeptide and rest are lipo-protein and lipo-polysaccharides)

iv. **Cytoplasm and organelles:** They contain soluble cytoplasmic constituents, nucleoid, mesosomes, ribosomes, lamellae (thylakoid) or vesicles (=chromatophores, found in photosynthetic bacteria) and some reserve materials like granules. Gas vacuoles or gas vesicles, chlorosomes, carboxysomes and magnetosomes are also special type of organelles found in some bacteria.

v. **Special structures:** Some bacteria form sporulation structures. Most characteristic spore structures are endospores, exospores, conidia, spores(akinetes), myxospores, cysts, bdellocysts are also formed by some genera of bacteria .

Morphological properties:

Genera	Shape	Size (μm)	Motility
<i>Xanthomonas</i>	Rod	0.4-1.0 x 1.2-3	Single polar flagellum
<i>Pseudomonas</i>	Rod	0.5-1.0 x 1.5-4	One or many polar flagella
<i>Erwinia</i>	Rod	0.5-1.0 x 1.0-3	Peritrichous
<i>Agrobacterium</i>	Rod	0.8 x 1.5-3	Sub-polar or peritrichous(1-4)
<i>Clavibacter</i>	Club-shaped/Rod	0.5-0.9 x 1.5-4	Non-motile/ motile with 1-2 polar flagella
<i>Ralstonia</i>	Rod		Single polar flagella
<i>Streptomyces</i>	Filamentous	0.5-2 (dia)	Non-motile
<i>Xylella</i>	Rod	0.3 x 1-4	Non-motile

Cultural characteristics:

Genera	Characters
<i>Agrobacterium</i>	Colonies are non-pigmented, smooth, gram -ve, oxidative metabolism
<i>Clavibacter</i>	Usually non pigmented, gram +ve, oxidative metabolism
<i>Erwinia</i>	Usually non-pigmented, gram -ve, fermentative metabolism
<i>Pseudomonas</i>	Green diffusible fluorescent, brown diffusible pigment or no pigment, gram -ve, oxidative metabolism.
<i>Xanthomonas</i>	Yellow, non-diffusible, gram -ve, oxidative metabolism
<i>Ralstonia</i>	Non-pigmented, creamy white colonies, oxidative metabolism, gram-ve
<i>Streptomyces</i>	Colonies are at first white coloured, small (1-10 mm dia), smooth, later become powdery velvety due to weft of aerial mycelium, gram -ve, produce variety of pigments depending on the substrates, oxidative metabolism
<i>Xylella</i>	Produce long filamentous strand when cultured, gram-ve, colonies are small, smooth or undulated margins, non-pigmented, aerobiotic/oxidative metabolism

Taxonomy, classification and nomenclature of bacteria: Taxonomy is the art of biological classification which includes identification as well as description of the basic taxonomic units (species) as completely as possible; it also determines the correct way of arrangement (cataloguing) of these units.

Major divisions of bacteria on the basis of cell wall structure

Kingdom : Prokaryotae

Division I : Gracilicutes (thin skin/cell wall, gram negative bacteria)

 Class : Scotobacteria

 Anoxyphotobacteria

 Oxyphotobacteria

Division II : Firmicutes (strong/durable cell wall, gram positive bacteria)

 Class : Firmibacteria

 Thallobacteria

Division III : Tenericutes(soft/tender cell wall, mycoplasma)

 Class : Mollicutes

Division IV : Mendosicutes (faulty cell wall)

 Class : Archaebacteria

Division and groups based on Bergey's Manual of Systematical Bacteriology (1984)

Kingdom : Prokaryotae

Division I : Cyanobacteria(blue green algae , myxophyceae)

Division II: Bacteria

 Part 1 : Phototrophic bacteria : 1 Order, 3 Family, 18 Genera

 Part 2 : Gliding bacteria : 2 Orders, 8 Family, 21 Genera

 Part 3 : Sheathed bacteria : 17 Genera

 Part 4 : Budding and Appendaged bacteria : 17 Genera

 Part 5 : Spirochetes : 1 Order, 1 Family, 5 Genera

 Part 6 : Spiral and curved bacteria : 1 Family, 2 Genera

 Part 7 : Gram-negative Aerobic rods and cocci : 5 Family, 14 Genera

 Part 8 : Gram-negative Facultative Anaerobic rods : 2 Family, 17 Genera

 Part 9 : Gram-negative Anaerobic bacteria : 1 Family, 3 Genera

 Part 10 : Gram-negative Cocci and Coccobacilli : 1 Family, 2 Genera

 Part 11 : Gram-negative Anaerobic Cocci : 1 Family, 3 Genera

 Part 12 : Gram-negative Chemolithotrophic bacteria : 2 Family, 17 Genera

 Part 13 : Methane producing bacteria : 1 Family, 3 Genera

 Part 14 : Gram-positive Cocci : 3 Family, 12 Genera

 Part 15 : Endospore forming Rods and Cocci : 1 Family, 5 Genera

 Part 16 : Gram- positive Asporogenous rod-shaped bacteria : 1 Family, 1 Genus

 Part 17 : Actinomycetes and related organisms : 4 Genera not assigned to any family;
 1 Family with 2 Genera; 1 Order with 8 Family and 31 Genera

 Part 18 : Rickettsias : 2 Order, 4 Family, 18 Genera

 Part 19 : Mycoplasmas : 1 Class, 1 Order, 2 Family, 2 Genera

Nutrition and effect of physiochemical factors on growth:

A. Nutrition: Many organic substrates are the sources, two nutrients viz. carbon (C) and energy which are important for bacterial growth. Certain bacteria e.g. *Pseudomonas* can use more than 90% organic compounds as a sole source of C and energy. Some bacteria can use two substrates (methane and methanol by methane producing bacteria) or only one substrate (cellulose decomposing bacteria). Bacteria need CO_2 (5-10%) for satisfactory growth on organic media. Thiamin (Vitamin B₁) is also required for the growth of bacteria. However, the bacterial species which can synthesise thiamin, do not require any special compound.

While bacteria are grown on/in artificial medium, the medium should have balanced mixture of necessary nutrients. Synthetic (ingredients are chemically known) and complex (ingredients are chemically unknown) media are used for artificial culture of bacteria. Commonly used elements in synthetic medium are K, Mg, Fe, Ca, Mn, Mo, Co, Zn, NH_4 and glucose (for C). For nitrogen fixing bacteria, N is not needed in media. Complex medium viz. nutrient medium contains peptone and beef extract and is used to grow wide range of micro-organisms including those microbes whose precise requirements (growth factors) are not known. Based on nutritional requirement also bacterial classification is made using some specific terms like autotrophic, heterotrophic, phototrophic, chemotrophic, lithotrophic and organotrophic.

B. Growth and Reproduction: In all cellular organisms, growth is achieved through cell multiplication. Hence, multiplication of a multicellular organisms result in an increase in size, while the multiplication of unicellular organisms results in increase in number. Growth in bacteria takes place through multiplication where one bacterium doubles at regular intervals (doubling time or generation time is 20-30 minutes) by binary fission (asexual reproduction). Thus number of bacterial cells increases exponentially. Formation of endospores, cysts, fragmentation, sporangiospores and conidia are some other means of asexual reproduction in bacteria. The sexual reproduction in bacteria is represented by transformation, conjugation, transduction and lysogenic conversions. The growth curve of bacteria can be plotted with four phases viz. lag phase (slow growth), log phase (exponential growth), stationary phase (no growth) and death phase (decline of living cells).

C. Effect of physical factors / forces on growth and reproduction:

- (i) **Temperature:** Bacteria can survive temperatures of 0° to 85°C or even more depending upon the species. On the basis of temperature requirement, bacteria are divided into 3 categories viz. psychrophilic (0 - 30°C , optimum 15°C), mesophilic (min. 5 - 25°C , opt. 18 - 45°C , max. 30 - 50°C) and thermophilic (min. 25 - 45°C , opt. 55°C , max. 60 - 93°C).
- (ii) **Moisture:** Bacteria are more aquatic than terrestrial and can survive in presence of high percentage of water.
- (iii) **Light:** Ordinary visible light does not affect bacterial activity. But different spectrum of light viz UV light, infra-red light have different effect on the activity of bacterial species.
- (iv) **Pressure:** Ordinary mechanical pressure can not affect bacterial cells. Principle of osmosis is the best used pressure for destruction of bacteria.

(v) **Hidrogen-ion concentration:** Suitable pH range for bacterial growth and reproduction is 5.0 to 9.0 .

Bacterial Genetics and Variability: Knowledge on the genetic system of bacteria was dull till 1940. Prior to this period, no definite nucleus had been demonstrated in bacteria although variability in bacterial cells was recognized well before. Only the development of science in Molecular Biology helped to recognize transfer of genetic material i.e. DNA to the daughter cells at the time of binary fission.

Variability among bacteria is resulted from the following processes:

- (i) **Conjugation:** Two compatible bacterial cells come into contact. Then the recipient female cell (F^-) receives the DNA from the donor male cell (Hfr). Thus genetic make up of both the cells is changed.
- (ii) **Transformation:** The bacterial cell absorbs DNA exuded by compatible cells or freed by dissolution of the cell-wall into the external medium.
- (iii) **Transduction:** This process is a “phage-mediated genetic transfer”. The bacterial viruses (bacteriophages or phage) can acquire DNA from one cell and transfer it to the other cells attacked by them. If attacked cell is not destroyed due to infection by the phage, it reproduces to form new races with different genetic character.
- (iv) **Lysogeny:** It involves association of genetic material of a virus with that of bacterium. Although it is different from above three processes, it also provides a permanent genetic modification of the bacterial genome.

Viruses

Matthew (1981) defined a virus as “a set of one or more nucleic acid template molecules, normally encased in a protective coat, or coats of protein or lipoprotein, which is able to organize its own replication within suitable host cells. Within such cells, virus production is (a) dependent on the host’s protein synthesizing machinery, (b) organized from pools of the required materials rather than by binary fission, and (c) located at sites which are non separated from the host cell contents by a lipoprotein, bilayer membrane”.

Many plant diseases which are now known to be caused by viruses had been encountered long ago. The causes of those diseases were not known. The first breakthrough was made by Adolf Mayer in 1886, in the Netherlands, while studying the highly contagious, mysterious disease of tobacco which he called “Mosaikkrankheit” i.e. mosaic like disease. He found that healthy plants could be infected by injecting the sap of diseased plants. He also observed that the unknown agent could be inactivated by boiling the sap. He concluded that the disease was the manifestation of a bacterium. In 1892, Ivanovsky confirmed Meyer’s report and further showed the sap to remain infectious even after passage through bacteria-proof filter. However, he claimed the incitant to be a microbe. But Martinus Beijerinck realized the causal agent to be something novel. His results further confirmed the findings of Meyer and Ivanovsky and also showed that the incitant could diffuse into an agar gel. Based on all these findings, Beijerinck, in 1898, concluded that the mysterious pathogen was not a bacterium, but a *contagium vivum*

fluidum i.e. contagious infective material or infectious living fluid. He thought the contagium to be able to reproduce itself in living plants and referred it as a virus.

Architecture of viruses and viroids

Morphologically, virus particles are (i) isometric (spherical, polyhedral) and (ii) anisometric (rigid or flexuous rods, bacilliform or bullet-shaped). Many isometric viruses have symmetric polyhedra which are either of three cubic symmetry i.e. tetrahedral, octahedral or icosahedral. Isometric particles measure the diameter 17nm (satellite virus of tobacco necrosis virus) to 70nm (reoviruses). The bacilliform viruses measure up to 300 nm length x 95 nm width (rhabdovirus group). The rod-shaped viruses having short rigid rod measure 114-215 nm length x 23 nm width (the tobaviruses) and those with long flexuous particles measure up to 2,000 nm length x 10 nm in width (the closteroviruses).

The rod shaped particles of tobacco mosaic virus (TMV) consist of protein sub-units (capsomeres) built up in a regular, helical array, with the RNA chain compactly coiled in a corresponding helix on the inside of the protein sub-units. The protein coat (capsid) and RNA genome surround an axial hole or canal. In membrane-bound viruses, the inner nucleoprotein core is called as nucleocapsid.

Viroids are smallest ($1.1\text{-}1.3 \times 10^5$ mol. wt.), simplest and non-encapsidated RNA. They consist of a single molecular species of circular or linear form.

Chemical composition: Plant virus particles consist of infectious nucleic acid (the genome), which is encapsidated within a protective protein coat or shell. The genome, essential for virus replication, is composed of ribonucleic acid (RNA in most groups of viruses) and deoxyribonucleic acid (DNA in the caulimovirus and geminivirus groups). The RNA and DNA may be single stranded (ss) or double stranded (ds). Besides these two basic components, an envelop of lipid or lipoprotein membrane is present in some plant viruses. Other components are metallic ions and polyamines present in varying amounts. Some enzymes are found in reoviruses and rhabdoviruses. Water constitutes 10-50 percent of the mass of virus particle.

The nucleic acid may be present as a single continuous strand (single molecular species) in a particle. It is called mono-partite genome. Some nucleic acid genomes have two or more pieces (molecular species) in different particles; usually they are not always encapsidated within separate protein shells. Such genomes are termed as bi-, tri-, or multi-partite or the viruses with divided genome.

In some RNA viruses, the genetic information is divided into two or more parts. They are called multi-component viruses and the individual components are not infectious alone. Hence two or more genomic elements are needed to cause infection and replication.

The genomic organization of viruses depicts structure and function of genes or cistrons. Some triplet bases called codons are responsible for expression of genes. There are two types of codons, (i) initiation codons (AUG, GUG) and (ii) termination codons (UAG, UAA, UGA) and they control functions of genes and translation products.

Nomenclature of viruses and classification: A number of addition and deletion was made in naming viral pathogens. Linnaean style of binomial nomenclature is not followed. Instead, plant pathogenic viruses are named based on the common or vernacular name of the affected host plant such as tobacco mosaic virus, rice dwarf virus, caulimoviruses, potato virus X and Y etc. Later, these vernacular names were further simplified by abbreviating them such as TMV for tobacco mosaic virus, CMV for cucumber mosaic virus, potex virus for potato virus X, CaMV for cauliflower mosaic virus etc. In addition to such names, a system of cryptogams was introduced to give concise information on the properties (immediate summary) of one virus for example:

TMV = R/1 : 2/5 : E/E : S/O
 (1st) (2nd) (3rd) (4th)

1st term : Type of nucleic acid (RNA, DNA)/number of strands of nucleic acid (1=ss, 2=ds)

2nd term : Molecular weight of nucleic acid in millions/ % of nucleic acid in infective particle

3rd term : Outline of particle shape (E=elongate, S=spherical, B=bacilliform)/outline of nuclear capsid (E, S, B)

4th term : Type of host infected (B=bacteria, F=fungus, I=invertebrate, S=seed plant)/ type of vector (Ap=aphid, Au=leafhopper, Cl=beetle, Fu=fungus, Ne=nematode, Th=thrips, W=whitefly, O=spread without vector, Se=seed transmitted)

A system of plant virus classification was introduced by International Committee on Taxonomy of Viruses (ICTV) based on the characteristics such as morphology of virus particle, type and quantity of nucleic acid, genomic structure and type of vector. For example

Classification based on particle morphology and type of nucleic acid:

- I. Elongated, Helical, ss RNA
 - A. Rigid
 - (a) Monopartite
 - (b) Multipartite
 - B. Flexuous, all monopartite
- II. Isometric
 - A. Single stranded RNA
 - (a) Monopartite
 - (b) Multipartite
 - (b1) With envelope
 - B. Double stranded RNA
 - C. Single stranded DNA
 - D. Double stranded DNA
- III. Bacilliform
 - A. Without envelop
 - B. With envelop

Grouping of plant viruses

Like families and genera cited in the classification of fungi and bacteria, plant virologists have been using “groups” for viruses. A total of 26 groups have been accepted by ICTV and some of those are,

1. Alfalfa mosaic virus group
2. Bromoviruses
3. Carlaviruses
4. Caulimoviruses
5. Comoviruses
6. Dianthoviruses
7. Geminiviruses etc.

There are about 11 unclassified virus groups are known, e.g.

1. Barley yellow mosaic virus group
2. Carnation mottle virus group
3. Rice stripe virus group
4. Satellite virus group etc.

Criteria for identification of viruses

Viruses causing plant diseases can be identified correctly by number of ways:

1. *Behaviour in host*: Host range, symptoms and their types, tissue restriction, type and location of intracellular inclusion bodies, seed transmissibility.
2. *Vector relation*: Taxa, acquisition and inoculation thresholds, persistence in vector, multiplication in vector, modes of transmission (e.g. transovarial transmission).
3. *Particle properties*: Shape and symmetry, size, presence or absence of envelope, capsomeric structure, sedimentation properties (number of components and sedimentation co-efficient); coat protein properties (no. of polypeptides and their molecular weight); properties of nucleic acid (RNA, DNA, strandedness, no. molecules and molecular weight, presence or absence of 5'-terminal M⁷Gppp, 5'-terminal VPg, 3'-terminal Poly (A)); electrophoretic mobility; isoelectric point, serological relationship.
4. *In vitro properties in crude sap*: This is determined by the tests viz. thermal inactivation point (TIP), dilution end point (DEP), longevity of virus *in vitro* (LIV).
5. *Cross-Protection tests*: Virus identity and strain relationship can be done. However, this sort of test is less applied now-a-days.

Important techniques for virus detection and identification:

1. *Electron microscopy*: used to know shape, symmetry, size, presence or absence of envelope and capsomeric structure.
2. *Immunosorbent electron microscopy* (ISEM).
3. *Serology*: The technique includes
 - (i) Precipitin tests (precipitin-tube test, precipitin-ring test, microprecipitin test).
 - (ii) Immunodiffusion tests (single, radial diffusion test, gel double-diffusion or Ouchterlony test)

- (iii) Agglutination test (slide-agglutination or chloroplast-agglutination test).
- (iv) Enzyme-linked immunosorbent assay (ELISA): It includes indirect ELISA and direct double antibody sandwich (DAS) ELISA.
- (v) Dot immunobinding assay (DIBA)
- (vi) Molecular hybridization analysis (spot hybridization or dot-blot technique)
- (vii) Monoclonal antibodies (MAb)

Multiplication and infection nature of plant viruses: The events in virus infection involve three steps: adsorption, penetration or entry and uncoating or disassembly. The initial contact between virus particle and host cell is referred to as adsorption or entry. The process during which the virion or its nucleic acid passes into the cytoplasm of the cell is known as penetration or entry. Uncoating is the removal of various components of the mature virion and subsequent release of viral genome and other constituents that plays a major role in establishing infection.

(i) Multiplication of virus in plants: The replication of RNA and DNA plant viruses differ from different groups of viruses or for individual viruses. The mechanism known for different groups of plant viruses are – ssRNA virus- monopartite genomes, ssRNA virus-bipartite genome, ssRNA virus- tripartite genome, dsRNA virus- monopartite genome, satellite viruses, helper viruses and satellite RNAs, dsDNA viruses. The progeny RNA moves out to cytoplasm where the assembly synthesized proteins and encapsidation of virion take place. The process continues till the host is alive and a large number of new virus particles are formed.

(ii) Accumulation and movement of viruses in plant: The nascent virus appears in the cell about 10 hours after infection. The concentration of virus varies based on the type of virus, temperature, nutrition and duration of light. The virions are found aggregated in amorphous or crystalline forms or they are dispersed in cytoplasm and nucleus.

In plant system, two stages of virus movement have been recorded. These are:

- a. Cell to cell or short distance movement: This type of virus movement takes place through protoplasmic bridges, the plasmodesmata. The plasmodesmata selectively allows passage to the macromolecules and thus virus can move through it with the help of virus-coded ‘movement protein’ mechanism.
- b. Movement from one part to another part of plant: This is a long distance movement of the viruses taking place through vascular system. The movement is faster in elongated young cells than in round and older cells. Moreover, virus moves fast at high temperature because the protoplasmic streaming and cellular activities are higher at high temperature. The nature of cells (parenchyma, xylem, phloem, sieve tubes) also determined rate movement of viruses in plant.

As a result of the multiplication and distribution of the viruses in the plant system, the host plant(s) are infected and exhibited varying degrees of disease symptoms.

Transmission of plant viruses: Viruses are distributed or transmitted from the infected plants to the healthy ones in various ways in nature. As the plant viruses can not penetrate cuticle of their hosts and hence they can enter into the host tissue through wounds only. The means of transmission are:

1. *Mechanical transmission*: The sap of the infected plant is manually transferred to the healthy plants. It is the easiest method of experimental inoculation.
2. *Graft transmission*: In this practice, if either the scion (shoot portion) or stock (root stock) is infected, the virus usually moves to the healthy partner which may later express visible symptoms of disease.
3. *Transmission through vectors*
 - (i) Insects: Some insect species are the vector of plant viruses which can carry/ transmit viruses from infected plants to the healthy plants e.g. aphid (potato virus Y, PLVR), white flies (tobacco leaf curl), beetles (cowpea mosaic virus), mealy bugs (cacao mottle leaf), thrips (tomato spotted wilt), lace bugs (sugar beet viruses), mites (sterility mosaic of arhar), leaf hoppers (beet curly top, rice tungro etc.), plant-hoppers (maize mosaic, maize rough dwarf), tree hopper (tomato pseudo curly top).
 - (ii) Nematodes: Five genera of nematodes viz., *Xiphinema*, *Longidorus*, *Paralongidorus*, *Trichodorus* and *Paratrichodorus* can transmit plant viruses.
 - (iii) Fungi: Some species of fungi can also transmit viruses e.g. *Olpidium brassicae* (tobacco necrosis), *O. cucurbitacearum* (cucumber necrosis), *Polymyxa graminis* (oat mosaic, wheat mosaic), *P. betae* (beet necrotic yellow vein) and *Spongopora subterranea* (potato mop top) etc.
4. *Dodder transmission*: Many viruses can be transmitted through dodder (*Cuscuta* spp.). Dodder transmission is used in the laboratory to transfer viruses from the hosts.
5. *Transmission through seeds and pollens*: Seed coat (testa), embryo, and also pollens of some plants can transmit viruses. e.g. alfalfa mosaic, barley stripe mosaic, bean common mosaic, lettuce mosaic are transmitted by both seeds and pollens of *Medicago sativa*, *Hordeum vulgare*, *Phaseolus vulgaris* and *Lactuca sativa*, respectively.

Basic characteristics of insect transmission: Virus transmission, specially in case of the aphid transmission, takes place by three ways viz. non-persistent (stylet borne), semi-persistent and persistent (circulative). These modes of transmission have been distinguished on the basis of acquisition feeding time, inoculation feeding period, latent period and multiplication or no-multiplication of the viruses within their vector etc. Apart from aphids, semi-persistent mode is recorded in mealy bug (*Planococcoides njalensis* - cacao swollen shoot virus) and leaf hopper (*Graminella nigrifrons* - maize chlorotic dwarf virus; *Nephrotettix impicticeps* - rice tungro virus) and persistent mode is recorded in leaf hopper (*N. cincticeps* - rice dwarf virus; *Agallia constricta* - wound tumer virus), plant hopper (*Peregrinus maidis* - maize mosaic virus), tree hopper (*Micruitalis malleifera* - tomato pseudo curly top virus), beetles (*Ceratoma trifurcata* - cowpea mosaic virus; *Phylloptreta* sp. – turnip yellow mosaic virus) and thrips (*Frankliniella fusca* – tomato spotted wilt virus).

Some viruses pathogenic to plant can be transmitted only in presence of a second virus (helper virus) in the host and this type is called dependent transmission. For example, aphid (*Myzus persicae*) transmits potato aucuba mosaic virus only if the source plant is also infected with potato virus A or Y.

Mycoplasma, Spiroplasma and Fastidious bacteria

Importance: Mycoplasma were known in animal pathology including human diseases. In 1988, they were first isolated and proved their Koch's postulates in bovine pleuropneumonia by Nocard and Roux. In plants, 'yellow' diseases were thought to be caused by some viral pathogens. Nullifying the role of viruses, Doi *et al.*, (1967) and Ishii *et al.* (1967) from Japan reported the involvement of mycoplasma like organisms (MLO) in causing 'yellow' diseases in plants. Little leaf of brinjal, grassy shoot of sugarcane, sandal spike are some of the important plant disease caused by MLOs (=Phytoplasma i.e. plant mycoplasma). In 1972, Davis *et al.*, observed a motile and helical microorganisms associated with corn stunt disease, they termed them as spiroplasma. Later, citrus stubborn disease was also reported fastidious bacteria from the phloem of clover and periwinkle plants infected with club leaf disease. The causal agents were called as rickettsia like organisms (RLO) or rickettsia like bacteria (RLB). Pierce's disease of grape, phony peach disease in peach, sugarcane ratoon stunting, alfalfa dwarf diseases are caused by fastidious vascular bacteria.

Morphological characters of Mycoplasma: Mycoplasmas have a prokaryotic cellular organization except the cell wall which is bounded by triple layer unit membrane and lack the ability to synthesize cell wall material. They are highly pleomorphic with small coccoid bodies, ring forms, pear shaped and rarely filamentous (branched or unbranched). Usually, they are non-motile and filterable through bacterial filters. They are very small and diameter ranges from 0.3-0.9 μm . They produce typical 'fried egg' colonies in cell free solid media and require sterol for growth. They are insensitive to penicillin, but inhibited by tetracycline and some specific antibody.

Morphological characters of Spiroplasma: Spiroplasmas are helical (spiral) mycoplasmas. Branched non-helical filamentous are also found. They measure about 120 nm in diameter and 15 μm long. They are motile, move by a slow undulation of the filament and probably by a rapid rotary a screw motion of the helix. Rest other characters are similar to those mycoplasmas.

Morphological characters of Fastidious bacteria: Fastidious bacteria develop within the vascular system of plants and hence they are categorized into two types viz., fastidious phloem-limited and fastidious xylem-limited bacteria. They are generally rod-shaped cells of 0.2-0.5 μm in diameter by 1-4 μm in length. They are bounded by a cell wall and a cell membrane, although in the phloem-inhabiting bacteria, cell wall appears more as a second membrane than as cell wall. The outer layer of the cell wall is usually undulating or rippled. They don't have any flagella. Nearly all fastidious vascular bacteria are Gram-negative and only few are Gram-positive.

Classification of Mycoplasma, Spiroplasma and Fastidious bacteria

A. Mycoplasma and Spiroplasma

Kingdom	:	Prokaryotae
Division	:	Tenericutes
Class	:	Mollicutes
Order	:	Mycoplasmatales
Family	:	1. Mycoplasmataceae Genus: <i>Mycoplasma</i>

2. Spiroplasmataceae
Genus: *Spiroplasma*
3. Acholeplasmataceae
Genus: *Acholeplasma*

B. Fastidious vascular bacteria : There is no well accepted classification (taxonomy) made so far for these organisms. Hence classification for Rickettsia (RLO) and Fastidious bacteria (e.g. *Xelella*) are mentioned below:

B1: Rickettsia (RLO)

Kingdom	:	Prokaryotae
Division	:	Gracilicutes (Gram-ve bacteria)
Class	:	Proteobacteria
Sub-class	:	Alpha proteobacteria
Order	:	Rickettsiales
Family	:	Rickettsiaceae
Tribe	:	Rickettsiae

B2. Fastidious vascular bacteria

Kingdom	:	Prokaryotiae
Division	:	Gracilicutes (Gram-ve bacteria)
Class	:	Proteobacteria
Sub-class	:	Gamma proteobacteria
Order	:	Not classified
Family	:	Not classified
Tribe	:	Not classified
Genus	:	<i>Xelella</i>

Reproduction of mycoplasmas: MLOs can reproduce by binary fission, by formation of spores (elementary bodies), by filamentous growth and budding. The chromosome replication starts at a fixed site followed by bidirectional progression. Further, the outline of chromosome replication of mycoplasmas is somewhat similar to that of *E. coli*. However, the process of mycoplasma cell reproduction has not yet been well classified.

Reproduction of spiroplasma: Cell division by budding, constriction followed by fission into unequal daughter cells are assumed to be the principal mode to reproduction in spiroplasma.

Reproduction of Fastidious bacteria: Binary fission gives rise to development of many hantle-like structures and forms in this organism. The resultants are pleomorphic bodies sometimes bounded by only one membrane.

Plant Pathogenic Nematodes

Nematodes belong to the Animal kingdom, and phylum Nematoda. Most of the important parasitic genera belong to the order Tylenchida and few under Dorylaimida. Important plant parasite species are *Meloidogyne incognita* (root knot nematodes), *Heterodera* and *Globodera* (cyst nematodes), *Tylenchulus semipenetrans* (citrus nematode), *Pratylenchus* (lesion nematode),

Ditylenchus (stem and bulb nematode), *Anguina* (seed-gall nematode), *Aphelenchoides* (foliar nematode) etc.

General morphology of nematodes: The body of the adult male is cylindrical, filiform, eel-shaped, round in cross section and tapering at each end. The anterior end is smooth, provided with papillae, leading to a buccal cavity and to oesophagus. Body is smooth, unsegmented without leg or other appendages. Plant parasitic nematodes mostly measure 300-1000 μm with some up to 4 mm long x 15-35 μm wide. The females of some species become swollen at adult stage and have pear-shapes (pyriform) or spheroid bodies. Nematodes can be easily observed under microscope. A valve is located at the junction of oesophagus and the intestine, the latter opening into the rectum and anus at the posterior end of the body. The entire body is covered with a colourless, impermeable (permeable only to water) smooth or transversely striated cuticle with a sub-cuticular and muscular layer.

Life cycle and reproduction of nematodes: Nematodes produce eggs. Eggs hatch into larvae. Appearance and structure of larvae are usually similar to the adults. Larvae start to grow and each larval state is terminated by molt. Nematodes have four larval stages. Usually, first molt occurs in the egg and the final molt differentiates into adult male and female. Fertile eggs are produced by females after mating with a male, or parthenogenetically in absence of males or can produce sperm herself. A life cycle from egg to egg stage is completed with 3 to 4 weeks or requires slightly longer period in cooler temperature.

Behaviour of nematodes in soil: Except free living nematodes, all the plant parasitic nematodes complete a part of the life cycle in soil. Being soil-borne microfauna, the activities of these nematodes are affected by soil temperature, moisture, aeration, soil texture and pH, organic matter, rhizosphere and various cultural operations. Population of nematodes is high in soil layer of 0-15 cm depth and sometimes they can live upto the depth of 150 cm or more. Generally, concentration of nematodes is extremely high in the rhizosphere of susceptible host plants.

Movement of nematode in soil is very slow and a nematode can travel a maximum of one meter per season. However, they can move faster at certain soil moisture level when pores are lined with thin film of water under water logging conditions. In gall forming nematodes, temperature-moisture interaction determines the emergence of larvae from galls. Most nematodes eggs hatch freely in water in absence of any special stimulus. Nematodes are spread in a local areas by farm equipments, irrigation, flood or drainage water, animal feet and dust storms while spread to a longer distance through farm produce and nursery plants.

Nematodes as vector of plant pathogens : Some species of nematodes viz., dagger nematode (*Xiphinema* sp.), needle nematode (*Longidorus* spp. and *Paralongidorus* spp.) and stubby-root nematodes (*Trichodorus* spp. and *Paratrichodorus* spp.) can carry plant viruses. Members of *Longidorus* and *Xiphinema* (family Longidoridae) transmit the polyhedral nepoviruses (type member : tobacco ringspot virus) while *Trichodours* and *Paratrichodorus* (family Trichodoridae) transmit the straight tubular tobraviruses (type member: tobacco rattle virus). Few examples of the nematodes as virus vectors are mentioned below:

S.No.	Plant virus transmitted	Nematode species involved as vector
1	Arabis mosaic	<i>Longidorus caespiticola, Paralongidorus maximus, Xiphinema index, Xiphinema spp.</i>
2	Brome mosaic	<i>L. macrosoma, X. coxi, X. diversicaudatum</i>
3	Carnation ringspot	<i>L. elongatus, X. diversicaudatum</i>
4	Cowpea mosaic	<i>X. basiri</i>
5	Grapevine fan leaf	<i>X. index and X. italiae</i>
6	Grapevine vein banding	<i>X. index</i>
7	Mulberry ringspot	<i>L. martini</i>
8	Tobacco ringspot	<i>X. americanum, X. coxi</i>
9	Tomato ringspot	<i>X. americanum, X. brevicolle</i>
10	Tobacco rattle	<i>Paratrichodorus minor, Trichodorus cylindricus, T. primitivus</i>

Phanerogamic Plant Parasites

Some flower and seed bearing higher plants (phanerogams) live parasitically on other living plants and can cause important diseases on agricultural crops and also in forest trees. They are classified in the following botanical families and genera,

1. Cuscutaceae (stem parasite)
Genus: *Cuscuta*, the dodders
2. Viscaceae (stem parasites)
Genus: *Arceuthobium*, the dwarf mistletoes of conifers
Phoradendron, the American true mistletoes of broad leaved trees
Viscum, the European tree mistletoes
Dendrophthoe, the giant mistletoes
3. Orobanchaceae (root parasite)
Genus: *Orobanche*, the broomrapes
4. Scrophulariaceae (root parasite)
Genus: *Striga*, the witchweeds

Identifying characters, reproduction and life cycle

1. **Dodder (Love-vine, Amarbel):** Dodder is slender, twining plant. The stem is tough, succulent, threadlike, curling, leafless and bearing minute scales in place of leaves. Stem is usually yellowish or orange in colour. They grow and climb in abundance on the wild and cultivated plants. Their haustoria penetrate the stem or leave of the host plant and absorb foodstuffs and water. Growth of the infected plants is suppressed and finally dies. Tiny whitish flowers arise in clusters from the stem and they produce numerous grey to reddish-brown seeds within few weeks of bloom. The seeds fall on the ground where they

either germinate immediately or remain dormant until next season. The seeds may be spread to new areas by animals, water, equipments and by mixing with crop seeds.

2. **Giant mistletoe (Loranthus)** : Mistletoes are semi-parasites of tree-trunks and branches. They have green leaves and many branches and hence grow like a small bush on the host. They do not have true roots and hence develop haustoria to draw nutrients from the vascular system of the host plant. Flowers are long, tubular, greenish white to red in colour and borne in clusters. Seed is fleshy, contains one seed, sweet in taste and usually eaten by birds and animals. The parasite is spread mostly through birds. Droppings of bird containing seeds get deposited on the other trees, mainly at the junction of a branch and main trunk. These seeds germinate, develop haustoria and establish on the host plant.
3. **Broomrape**: Broomrape is a complete root parasite. It affects tobacco mostly and many other Solanaceous and Cruciferous plants. The parasite has a stout, fleshy stem of 10-15 cm long. The stem is pale yellow or brownish red in colour and is covered by small, thin, brown, scaly leaves. Flowers are white and tubular and appear in the axil of leaves. Seeds are very small, black in colour and can remain viable in soil for several years. Roots are haustoria-like, can penetrate the roots of the host for nutrition. The affected plants become stunted and may die.
4. **Witchweed**: It is a semi root parasite but obligate in nature. Commonly affected plants by this parasitic plant are sugarcane, cereals, maize and millets. *Striga* is a small plant with bright green, slightly hairy stem and leaves. The weed grows 15-60 cm high in clusters. Leaves are long and narrow in opposite pairs. Flowers are small, brick red or yellowish or almost white with yellow centers, appear throughout the season. Tiny brown seeds are produced in each capsule and thus a single plant can produce 50,000-500,000 seeds. The seeds can remain viable for 12-40 years. Roots are watery white in colour without root hairs and hence obtain nutrients by haustoria from the host plant. The life cycle from seed germination to first seed setting on the developed plant needs 90-120 days.

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